Current Measurements in the Grand Manan Channel

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ABSTRACT

Currents at a series of stations across the north and the south entrances of the Grand Manan Channel and across a section in its northern approaches have been measured during complete tidal cycles. The features of the flow observed during each series have been described. The principal flow is along the axis of the channel. Stronger currents on the ebb tide indicate a dominant flow towards the south.

INTRODUCTION

The Grand Manan Channel is a body of water lying between the Island of Grand Manan and the Maine coast. The bottom of this channel is almost level and its sides precipitous, giving it a nearly rectangular cross section. Currents, associated with the extreme tides of the Bay of Fundy, carrying water over the shoals to the south and through the irregular features in the northern approaches, produce a body of virtually homogeneous water in the channel (Hachey, 1931; Watson, 1936; McLellan, 1951). Much has been written concerning the water movements in the channel although the factual data presented have been few.

This survey was designed to add to the recorded data, using a new instrument which has some distinct advantages in the study of such an area.

Dawson (1908) reported hourly directions and magnitudes of currents for a station (Lat. 44° 45′ 05″ N., Long. 66° 55′ 55″ W.) in the centre of the channel, which was occupied from August 29 to September 1, 1904. Measurements were made with a current meter placed at a depth of six metres and registering electrically. The current values were adjusted to correspond with the average tidal range of 21 feet (5.9 metres) at Saint John. The current vector rotated clockwise, showing a maximum velocity along the axis of the channel of 2.15 knots (110 centimetres per second) during ebb, and 2.65 knots (136 centimetres per second) during flood.

Mavor (1922) interpreted Dawson's data for this and other stations to show a residual clockwise circulation around Grand Manan Island. However, in a later paper (Mavor, 1923), where temperature and salinity observations were considered, he concluded "that it is unlikely that great general movement of the water could occur where the resistance to the tide is such as to cause great mixing".

Bigelow (1924) referred to this clockwise circulation but it is probable that his information was drawn from the reports of Dawson and Mavor.

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Watson (1936), from a study of the distribution of temperature, salinity and density in two sections across the channel, inferred that "the residual current is directed northward but is small".

CURRENT SURVEY IN 1950

From October 3 to 5, 1950, H.M.C.S. *New Liskeard* was made available for a current survey of the Grand Manan Channel. The ship was equipped with a Geomagnetic Electrokinetograph (von Arx, 1950) which permitted underway measurement of surface currents.

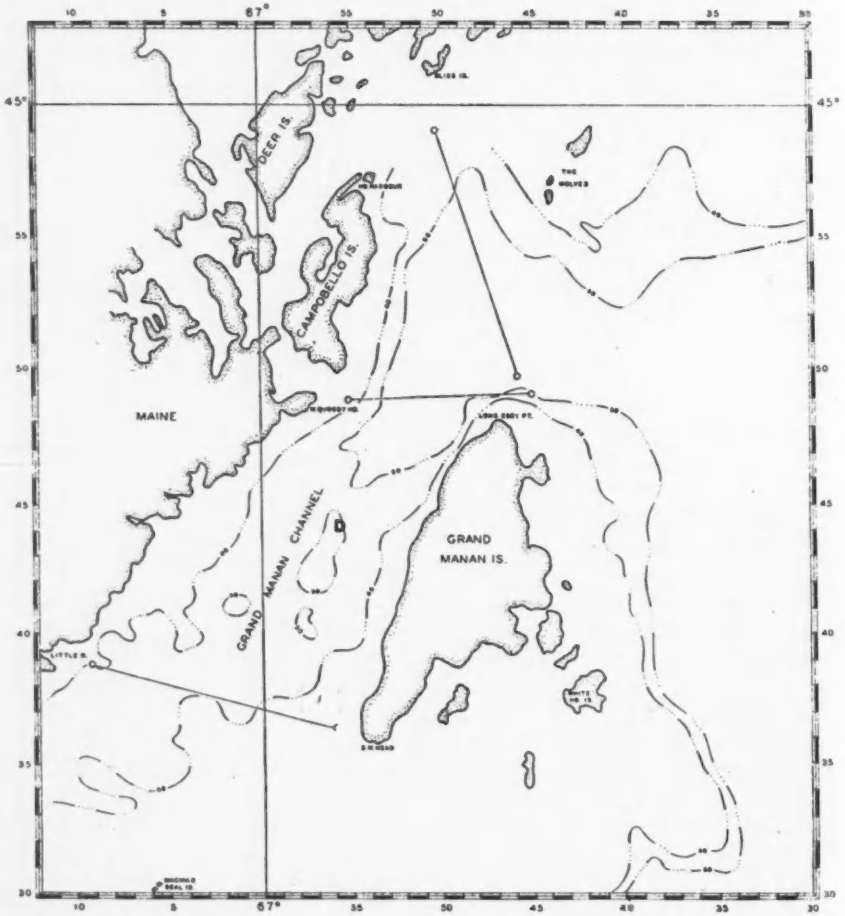

FIGURE 1. The Grand Manan Channel area showing bottom topography and lines of current observations. (Dawson's 1904 station is indicated by the letter "D".)

Three lines were laid down, one across each end of the channel and one in its northern approaches (Figure 1). Steaming at eleven knots back and forth over the base course, jogs were made, following the sailing plan A2 (von Arx, 1950), at intervals of approximately twenty minutes. This procedure gave data for some five current vectors on each crossing of the line. Six or more crossings of each line were made during the thirteen hour periods. Details of the three lines are given in Table I.

TABLE I. Lines of current observations in the Grand Manan Channel.

A.	*Grand Manan Channel—Southern End*
	From: 44° 38.8′N, 67° 9.2′W
	To: 44° 36.4′N, 66° 55.9′W
	Number of crossings 7
	Number of current vectors 34
	Time Oct. 3, 1950—11:05 to 23:42 A.S.T.
B.	*Grand Manan Channel—Northern End*
	From: 44° 48.8′N, 66° 55.2′W
	To: 44° 49.1′N, 66° 45.2′W
	Number of crossings 9
	Number of current vectors 37
	Time Oct. 4, 1950—1:15 to 13:57 A.S.T.
C.	*Grand Manan Channel—Northern Approaches*
	From: 44° 49.7′N, 66° 46.0′W
	To: 44° 59.1′N, 66° 50.3′W
	Number of crossings 6
	Number of current vectors 32
	Time Oct. 4, 1950—14:46 to Oct. 5 2:25 A.S.T.

The survey was made during neap tides and the tidal range for the port of Saint John was 14 feet (Tide Tables for the Atlantic Coast, 1950). The mean tidal range for this port is 21 feet (Dawson, 1908).

THE GEOMAGNETIC ELECTROKINETOGRAPH

The Geomagnetic Electrokinetograph ("G.E.K." or "jog-log") is a current meter which can be operated from moving vessels, developed by von Arx (1950) of the Woods Hole Oceanographic Institution. It consists of a two-wire cable towed at some distance behind the ship, each wire terminated by a non-polarizing electrode, one of which is at some distance behind the other. This cable, together with the water extending between the electrodes, constitutes an electric circuit. In it, electromotive forces arise when it has a component of velocity perpendicular to its length, so that it cuts across the vertical component of the earth's magnetic field. This electromotive force, E, is given by $E = VH_zL.10^{-8}$ volts where V is the velocity component in centimetres per second at right angles to the trailing cable, H_z the vertical intensity of the earth's magnetic field in oersteds and L the length of conductor in centimetres. A recording potentiometer registers the potential difference at the inboard cable terminals. This is equal to the electromotive force induced in the extra length of cable to the more distant electrode. Though an equal electromotive force is induced in the water, which is itself a moving conductor, this is essentially short circuited by stationary water layers

below and the conducting bottom of the channel. The two electrodes are thus at virtually the same potential.

In the ideal case, with a shallow current running over a very deep stationary layer, the velocity component of the water transverse to the cable is exactly given by $V = \frac{E}{H_z L} \cdot 10^8$ and, for a given H_z, L may be chosen so that the potentiometer reading corresponds with the velocity in knots.

In shallow water and/or with deep currents the electromotive force induced in the moving water is not completely offset, and the recorded potential is somewhat less. To compensate for this, the potentiometer reading is multiplied by a correction factor "k", which must be calculated from theoretical considerations, measured by simultaneous determination of current by a different method, or estimated from empirical data. Von Arx (1950) has published the results of a large number of experimental determinations to assist in selecting "k". In any case, the relative comparison of currents, and the calculation of directions may be done without a knowledge of the "k" value.

In very shoal water (less than 10 metres deep) von Arx found "k" to range from 1.5 to 15. In water 10-100 metres deep on the continental shelf "k" values averaged less than 2, while beyond 150 metres the "k" factor averaged 1.05. In this investigation a "k" factor of 2.0 was used. This was arbitrarily chosen to give current values comparable to those reported by Dawson (1908).

Mutually perpendicular current vectors are obtained by interrupting the ship's course with a rectangular jog and return at approximately twenty-minute intervals.

Composition of these two vectors provide the total current and the direction. The latter is, of course, independent of the value of the "k" factor.

Observations in the Grand Manan Area

The reduction of the electrokinetograph data was carried out according to the procedure described by von Arx. The zero point, which is the reading corresponding to zero velocity, was taken as the mean value of the reading before and after reversing the electrodes by a change in course of one hundred and eighty degrees. A separate zero was thus found for each jog. Random variations up to some 0.2 knots (10 centimetres per second) were found to occur in this value. A zero point based on a running mean of the individual zeros was also used to compute current components. No large differences were found with the two methods and only the data based on individual zeros are used here.

The instrument readings were corrected for the local value of the vertical component of the earth's magnetic field, $H_z = 0.540$.

Results of this current survey are presented in three diagrams, Figures 2, 3, and 4, one for each line of observation (Figure 1). In each diagram the mean course of the ship is shown. On lines parallel to this, showing the successive crossings of the channel section, the current vectors are represented to scale. The origin of each vector shows the position along the mean course at which the observation was made. The time (A.S.T.) is given for each observation. Times

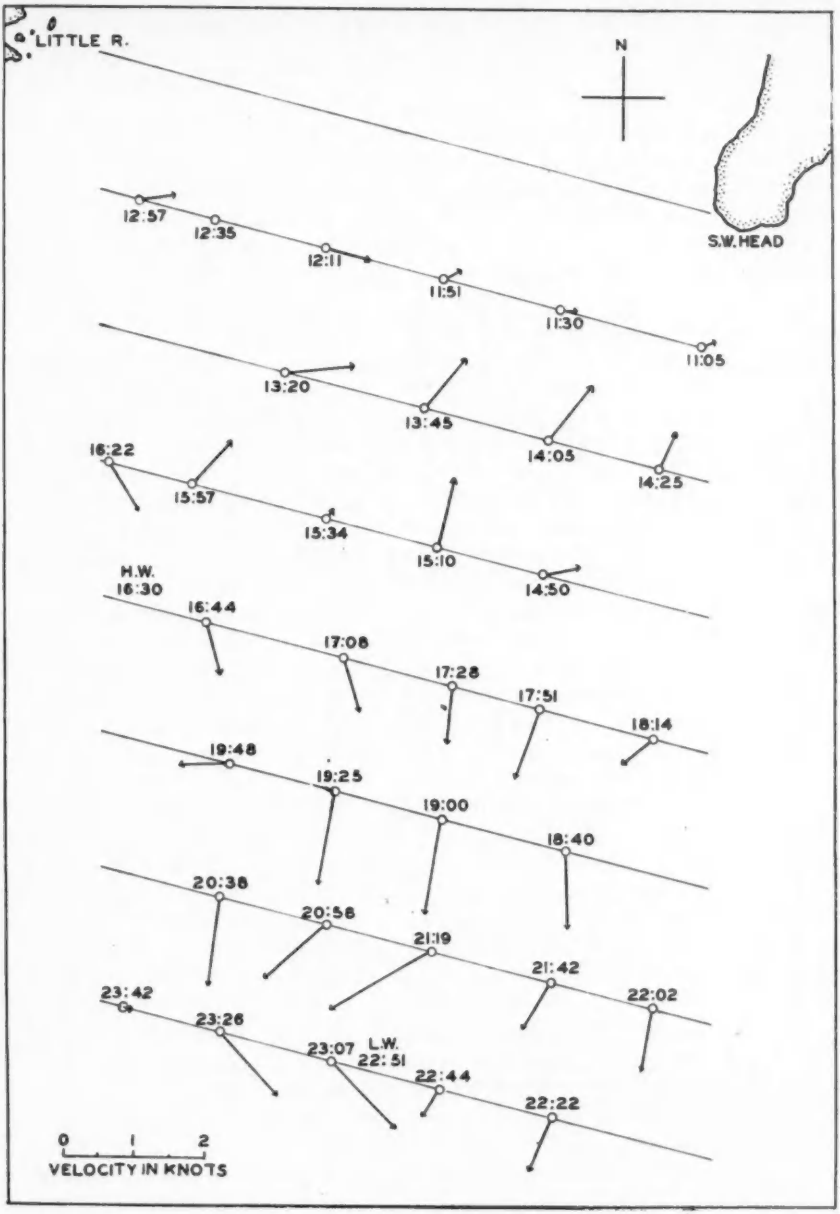

FIGURE 2. Current vectors observed in the southern end of the Grand Manan Channel: Little River to South West Head, 3 October, 1950.

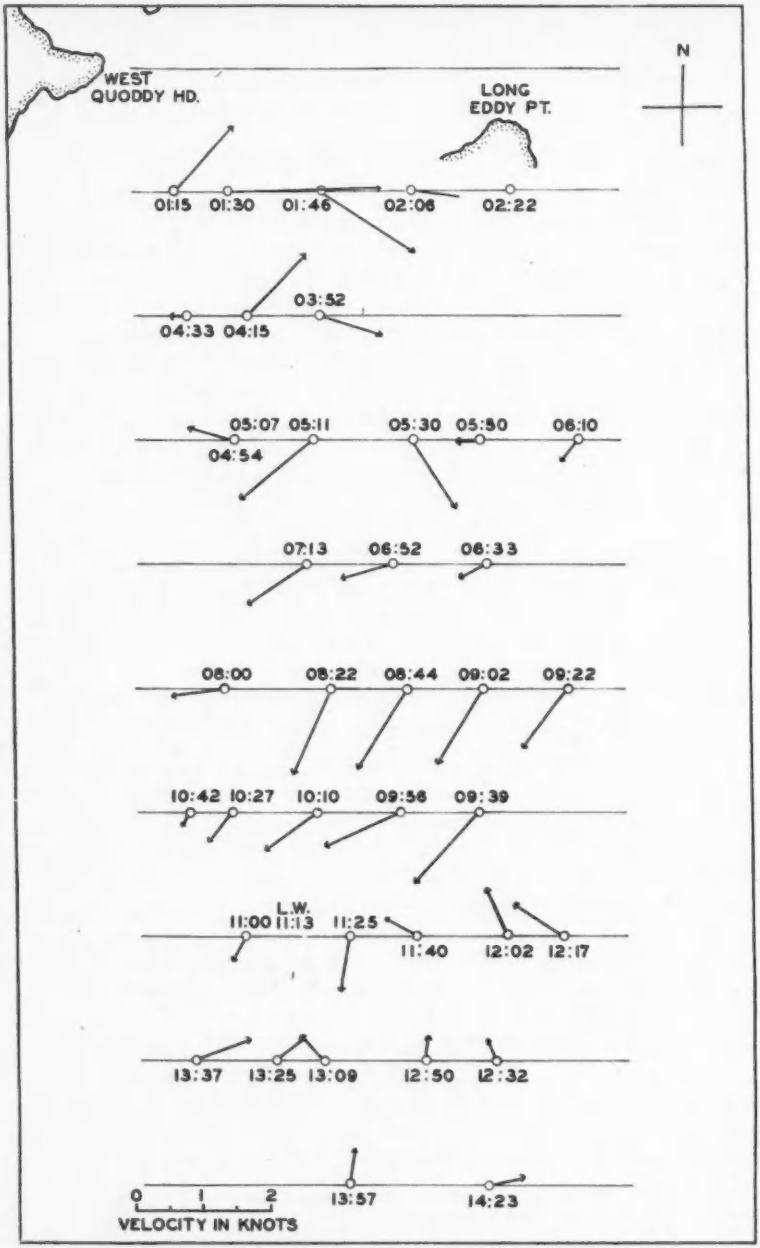

FIGURE 3. Current vectors observed in the northern end of the Grand Manan Channel: West Quoddy Head to Long Eddy Point, 4 October, 1950.

of high and low water for the port of Saint John are also shown in the figures.

(*a*) SOUTHERN END, FIGURE 2. On the flooding tide the currents were small, and predominantly eastward until three hours before the time of high water (Saint John), when they increased to approximately one knot directed towards the northeast. Thereafter they became less regular, as evidenced at 15 : 34 hours when a velocity of 0.16 knots (8.3 centimetres per second) toward the northeast was observed between 1.08 knots (55.6 centimeters per second) and 0.88 knots (45.2 centimetres per second) vectors. The 16 : 22 hour observation, at the extreme west of the section showed a southward component which appeared before the time of high water. At this end of the section an eastward component persisted after high water.

South of Little River the trend of the Maine coast changes abruptly, and this, coupled with the resistance offered by the shoals to the southwest of Grand Manan, probably tends to direct the flooding tide eastward.

Currents on the ebbing tide were noticeably stronger than on the flood, setting in to the south immediately at the time of high water, at approximately 0.8 knots (41 centimetres per second) and thereafter increasing to 1.5 knots (77 centimetres per second). After half-ebb the currents veered to the southwest, reaching a velocity of 1.8 knots (92.5 centimetres per second) in the centre of the section. The southward flow persisted after the time of low water, while a strong eastward component developed on the western half of the section.

The largest currents were observed near the centre of the section throughout.

(*b*) NORTHERN END, FIGURE 3. On the flooding tide, at the western end of the section, there was considerable variation in current strength and direction. Here the flood, which was observed at the beginning and end of the series, began with northeast currents, changing to east and southeast currents at half-flood. Towards high water westward flow was observed at the extreme west of the section, indicating that flooding of Cobscook Bay had become an influence.

The currents in the eastern end of the section were northwestward in the first hour after low water, followed by weaker northward currents. Unfortunately several observations were missed in this part of the series.

On the ebb tide there was a well defined pattern of southward flow and a distinct westward component in all but one vector, with velocities increasing to to 1.5 knots (77 centimetres per second) at half-ebb. It is obvious that the retreat of waters from the Bay of Fundy proper was channelled through this passage to a marked degree.

(*c*) NORTHERN APPROACHES, FIGURE 4. Currents in this section were of considerably less velocity than in the other sections and there was a large velocity component along the base course direction. In the northern half of this section southward flow was observed throughout the tidal cycle with a component across the section, into the channel, at all times. A maximum velocity of 1.3 knots (67 centimetres per second) was observed at low water.

In the southern half of the section, for a period of five hours, approximately from the half-ebb to the half-flood, the predominant currents were strong, approaching a maximum of 2 knots (103 centimetres per second). Their direction was southward with always an appreciable component across the section into

the channel. For an equal period centred on the high water, eastward currents out of the channel region prevailed.

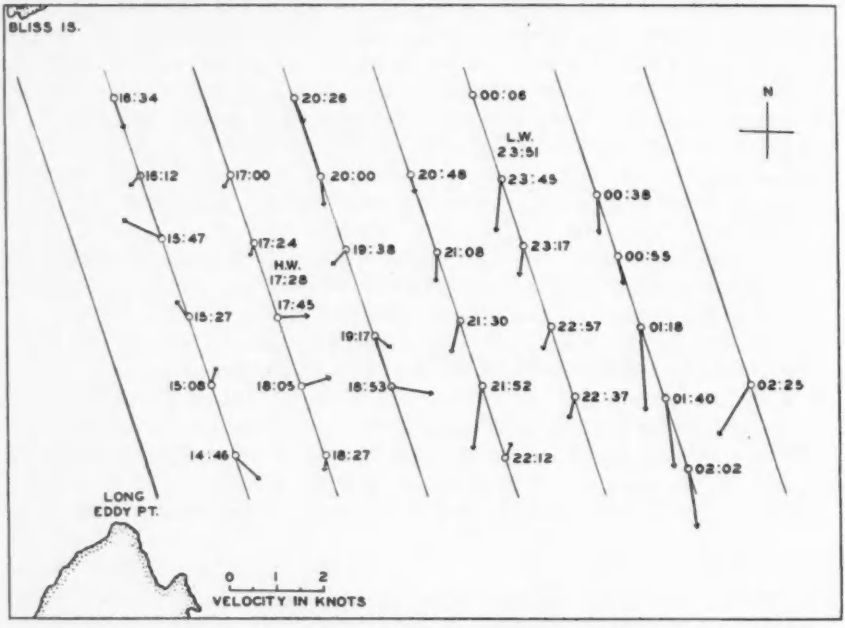

FIGURE 4. Current vectors observed in the northern approaches to the Grand Manan Channel: Long Eddy Point to Bliss Island, 4 and 5 October, 1950.

NON-TIDAL CURRENTS

Dominant flow to the southward through the channel is indicated in all three sections. The average of the velocity components normal to the section was found for each section during a whole tidal period. From this the net flow in cubic metres per tidal cycle was calculated. In making these calculations, it was assumed that the indicated surface velocities persisted unchanged to the bottom. This assumption is supported by Dawson's (1908) statement: "Almost everywhere the current is as strong down to a depth of 30 fathoms as it is on the surface", by the extreme lack of vertical stratification found (McLellan, 1951) in the same season, and by the tidal nature of the currents. No observations in support of this assumption were made, however. At the time of this survey the moon was near its maximum declination resulting in a marked inequality in successive tides which would account for a resultant flow up to some ten per cent of the mean tidal flow. Adjustment was made to offset this inequality.

Table II shows the results of these calculations which indicate a southward flow through the three sections of 12×10^9, 7.5×10^9, and 6.2×10^9 cubic metres per tidal cycle of 12.4 hours, with a mean value of 8.6×10^9 cubic metres per tidal cycle.

This pattern may be much altered by the tidal range and meteorological factors. The southward flow is in disagreement with various interpretations of Dawson's data which were taken over a 67 hour period when the tidal range was 19 feet (Dawson, 1908). The use of data from Dawson's single station to give a general picture of persistent dominant flow through the channel is probably not justified. A further and more extensive study of the area will be necessary before a complete description of the water movements in the channel can be made.

SUMMARY

Current measurements at a series of stations across the north and south ends of the Grand Manan Channel and across its northern approaches have been made through complete tidal cycles. These observations were obtained with the geomagnetic electrokinetograph which provided current directions and magnitudes of better than relative significance.

At the time of this survey a system of strong southerly currents was observed on the ebb while flood currents were smaller and less systematic.

The trend of shore lines and the submarine topography have marked influences upon the flow patterns in the channel and approaches.

The residual flow across each section was found to be through the channel to the south. Approximate calculations of the magnitude have been made for each section and found to be of the same order of magnitude, 8.6×10^9 cubic metres per tidal cycle.

ACKNOWLEDGMENTS

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TABLE II. Residual flow through the lines of observation in the Grand Manan Channel.

	South section A	North section B	Approaches C
Mean residual current			
(knots)	0.31	0.24	0.10
(centimetres per second)	16.	12.	5.1
Length of section			
(nautical miles)	11.5	7.5	13
(kilometres)	21.3	13.9	24.1
Mean depth			
(fathoms)	43	53	62
(metres)	79	97	113
Residual flow (cubic metres per tidal cycle)	12×10^9	7.5×10^9	6.2×10^9
Residual flow (cubic metres per tidal cycle)	Mean value 8.6×10^9		

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The Biology of the Surface Zone Zooplankton of a Boreo-Arctic Atlantic Ocean Area[1]

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CONTENTS

Introduction	224
History	224
Hydrography	225
The Investigation	231
Object	231
Apparatus and material	232
Method of procedure	232
Discussion of Results	234
Synopses of the species	234
Relative numbers	249
Absolute numbers	252
Transparency	253
Bioluminescence	256
Seasonal water-mass exchange	257
Conclusions	259
Summary	259
Acknowledgments	260
Bibliography	261

ABSTRACT

Zooplankton samples were taken from the surface zone waters of the central Labrador Sea at International Ocean Station "B" (56°–30′N., 51°–00′W.) at weekly intervals throughout one calendar year for the purpose of determining the composition of the zooplankton, the seasonal progression, fluctuations and pertinent physical factors. An attempt was made to correlate the physical and biological factors.

Ships of the United States Coast Guard and the Royal Canadian Navy were used as collecting units, and these were provided with nets, samplers and other equipment with which to carry out the shipboard phase of the investigation. Mid-day, 20 minute oblique hauls from 150-0 metres were made with the Clarke-Bumpus plankton sampler using No. 2 and No. 12 mesh silk nets, along with bathythermograph and Secchi disc lowerings. Later in the day, but at least one hour after dark, an open half-metre net 20 minute surface tow was made for additional qualitative data. Bioluminescence records also were obtained at this time.

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[1]A modification of a thesis prepared at the Narragansett Marine Laboratory, University of Rhode Island, and submitted in partial fulfilment of the requirements for the degree of Master of Science in Biological Oceanography.

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All available physical and biological data pertaining to the area under investigation were examined to provide a basis for comparison.

Synopses of the species found in the material are presented individually, including their seasonal occurrence, probable breeding seasons, numerical and economic importance, and values as indicator forms. In all, 61 species in seven phyla, 10 classes and 17 orders are represented.

The zooplankton population of the surface zone in the central Labrador Sea is characterized by relatively few species, but at the same time by large numbers of individuals. The plankton consists mainly of *Calanus finmarchicus*, *Thysanoessa longicaudata*, *Oithona atlantica*, *Scolecithricella minor*, *Oikopleura labradoriensis* and *Eukrohnia hamata*. The remainder of the species assume comparatively minor importance in the economy of the region.

The main augmentation season was found to occur generally in late summer, although mid-winter breeding was noted for a few animals. The zooplankton of this region was found to be distinctive, being consistently oceanic, but neither true arctic nor true boreal. Definite biological evidence was obtained that indicated the influx of boreal-subtropical surface waters into the area in winter.

Extinction coefficients determined from white Secchi disc readings are graphed, as are comparisons between black and white disc readings. It was concluded that the great variations of transparency were caused by fluctuations in the amount and kinds of phytoplankton and detritus in the water, and that the zooplankton density had little effect on water clarity.

No direct correlation was noted between the occurrence of bioluminescence and individuin species or planktonic groups, but it was found that the greatest bioluminescence was observed al the summer and fall.

INTRODUCTION

History

In 1949 Dr. Charles J. Fish was awarded a United States Navy contract for a plankton investigation for two open ocean areas. The program has had as its objectives a determination of the seasonal variations in the size and composition of the plankton population of the surface zone, and correlation with environmental factors. The United States Coast Guard offered to cooperate with the program and permitted its Ocean Station vessels occupying International Ocean Stations "B" and "E" to be used as collecting units. The Royal Canadian Navy assisted by collecting data from H.M.C.S. *St. Stephen* during her patrol of Station "B". Officers of the fourteen vessels involved in occupying Station "B" during the present phase of the investigation were first trained in the use of the Nansen bottle, Clarke-Bumpus quantitative sampler and half-metre nets at the Narragansett Marine Laboratory, and these in turn trained the relieving officer.

The zooplankton collections and associated data from one of the two locations, Station "B" (56°—30′ N., 51°—00′ W.), were assigned to the author for study. As far as is known this represents the first opportunity to obtain a continuous record of the annual cycle of the pelagic population in any open ocean area, and it has brought to light significant concepts of boreo-arctic oceanic population biology.

Nansen bottle samples taken weekly in conjunction with the zooplankton net hauls are being assigned to the Bingham Oceanographic Laboratory of Yale University for phytoplankton analysis. It is anticipated that these findings eventually will be collated with the present and continuing zooplankton data to form a more nearly complete biological study of the region.

Hydrography

The Labrador Sea comprises that section of the North Atlantic Ocean bounded in the north by Davis Strait, in the east by Baffin Land and Labrador, in the west by Greenland and the Reykjanes Ridge, and has open access to the

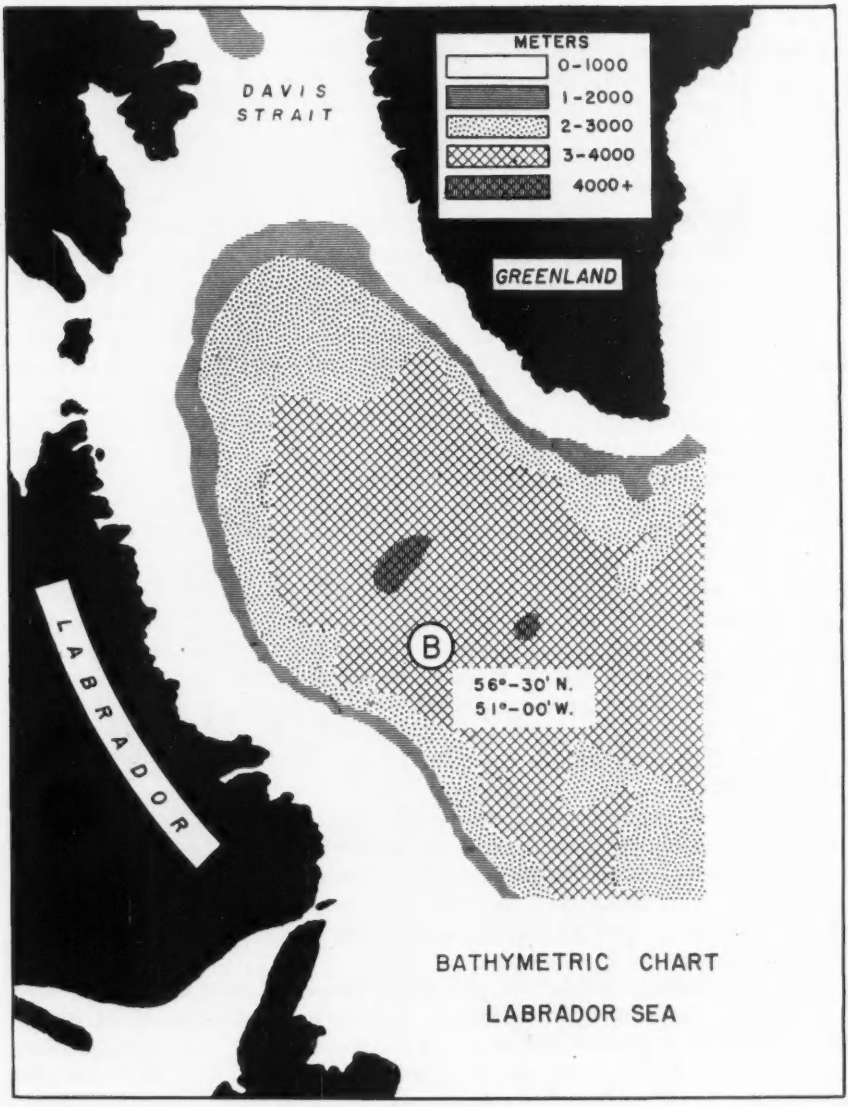


Figure 1. Bathymetric chart, Labrador Sea.

Atlantic Ocean proper in the southeast. The bathymetric chart (Figure 1) illustrates the topographic features of the area and shows the comparatively steep continental shelf near Greenland as opposed to the broad, sweeping shelf on the Labrador side. The "bridge" of the Davis Strait shoals to a depth of slightly less than 700 metres and then falls off again to the north to soundings of more than 2000 metres. These topographic features in this lesser-known region of the Atlantic have been defined by Smith, Soule and Mosby (1937).

The basin of the Labrador Sea is surrounded by great ocean currents that are of decided importance in influencing the biology of the area. The currents involved are the East Greenland Current, Baffin Land Current, Labrador Current, Irminger Current and, to some extent, the North Atlantic Drift. The East Greenland Current hugs the adjacent coast as it flows southward, then sharply rounds Cape Farewell and veers northward up the western Greenland coast to become the West Greenland Current. This latter current, according to Smith, Soule and Mosby (1937), is composed of two types of water with greatly differing characteristics: (*a*) that close inshore distinguished by its cold nature (less than 3.0°C.) and (*b*), that farther offshore, and about 100 metres deeper, shown by high salinities ranging up to 35.00 parts per mille. The inshore water is East Greenland arctic water, while the offshore component is of Irminger-Atlantic origin intruded from the open Atlantic. There is evidence that this Irminger-Atlantic water sinks as it progresses northward, and gradually mixes to homogeneousness within the Labrador Sea.

The Baffin Land Current becomes the Labrador Current as soon as it passes Resolution Island and begins to flow over the continental shelf off Labrador. This Baffin Land Current origin appears to be a mixture of West Greenland Current deflected westward at Davis Strait plus the influx of water from the western side of Baffin Bay. The Labrador Current contains not only the composite waters of the Baffin Land Current, but also the modifying elements of lower salinity from the outflow from Hudson Strait. With origins such as these, it is reasonable to find that Labrador Current water is characterized by low salinites and temperatures. In both the case of the West Greenland Current and the Labrador Current, there often appears an associated seaward countercurrent (Soule, 1950).

On reaching the "Tail of the Banks", part of the Labrador Current is deflected radically by the Atlantic Drift (Gulf Stream) and is returned northward, then eastward as the water reaches a latitude of 50° to 55° N. The remainder of the current flows generally and perhaps intermittently westward around Cape Race over the continental shelf and gradually proceeds toward the Gulf of Maine.

The United States Coast Guard cutters *Marion* and *General Greene* explored the Labrador Sea from 1928 to 1935, also the Danish steam barkentine *Godthaab* carried out oceanographic explorations in the area at about the same time. Since that time, the United States Coast Guard, in conjunction with its duties with the International Ice Patrol, has made oceanographic cruises to the area almost yearly and thereby has obtained much information regarding the circulation

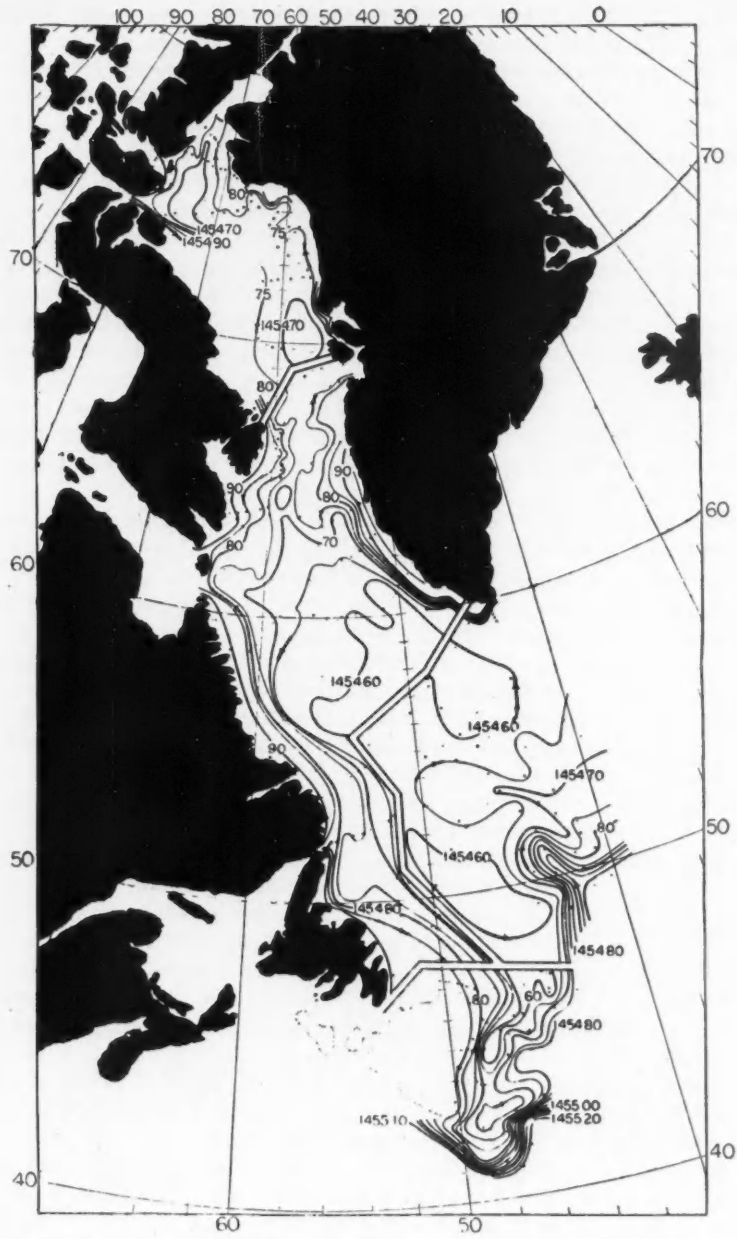


FIGURE 2. Dynamic topography, 1500-0 decibar surface. (From U.S. Coast Guard Bulletin 19, part 2.)

system of the region. Most of the observations made by these vessels have been limited to the physical aspects of temperature, salinity, oxygen, etc., by standard oceanographic means. More recently, the Coast Guard cutter *Evergreen* has made use of the Geomagnetic Electrokinetograph (von Arx, 1950) in determining the velocity of the surface currents. When the factors of salinity, temperature and depth of sample are substituted in Bjerknes' hydrodynamic formulae, the general circulation pattern may also be determined. Figure 2 represents such a circulation pattern as a composite of the dynamic topography for the years 1928-1935 with reference to the 1500 decibar surface. In interpreting the figure it must be remembered that the isobaths do not illustrate a synoptic situation, that they represent approximate streamlines rather than trajectories, and that the composite does not include wintertime observations. Also, the Bjerknes' theorem is based on a given reference plane of *assumed* zero motion, and therefore gives the concept of motion relative to that plane. Actually, selection of the 1500 decibar surface was carefully considered as being the proper reference plane in this case, and the error resulting from the difference of motion between the plane and the bottom of the sea is negligible except near the West Greenland Coast (Soule, 1940).

From Figure 2 it is impossible to determine from which side of the Labrador Sea neritic conditions would be more likely to influence Station "B" near the centre of the sea. However, a study of the historical weather charts shows that such conditions probably came from the northern Labrador region in 1950, provided that they were restricted to the upper surface layers of water. In any case, these instances must be rare indeed, because of the ecological barriers imposed by the currents between the central sea and the shore itself. The single occurrence of a few specimens of the neritic *Evadne nordmanni* and another instance of finding the intertidal alga *Ascophyllum* tends to confirm this hypothesis. Consequently, selection of Ocean Station "B" precisely in the dynamically weakest position of the Labrador Sea, affords the best possible location for the study of boreo-arctic plankton free from direct coastal influence.

Figure 3 shows a more-or-less "typical" cross sectional view of the Labrador Sea with respect to temperature and salinity cutting almost exactly across Station "B". The constancy of the "core" of the temperature inversion at first amazed the investigators, but Soule (1950) now believes that there may be a cyclic trend whereby the temperature of the core slowly varies. In 1934 the temperature was 3.13°C., in 1940 it was 3.27°C., and recently (1950) it has receded to more "normal" value of about 3.20°C. At least once, in 1935, the encircled core has been missing, the temperature decreasing with depth to the bottom. Just what effect these cyclic changes have upon the fauna of the deep water regions of the area is not known, but it is doubtful that a slow change of about 0.2°C. could be reflected in a detectable biological change.

The lower half of Figure 3 illustrates a typical salinity profile of the same section. Again the intermediate water is characterized by homogeneous salinity of about 34.88 parts per mille. The little well of high-salinity surface water at station No. 1758 is apparently a displacement from the Irminger-Atlantic

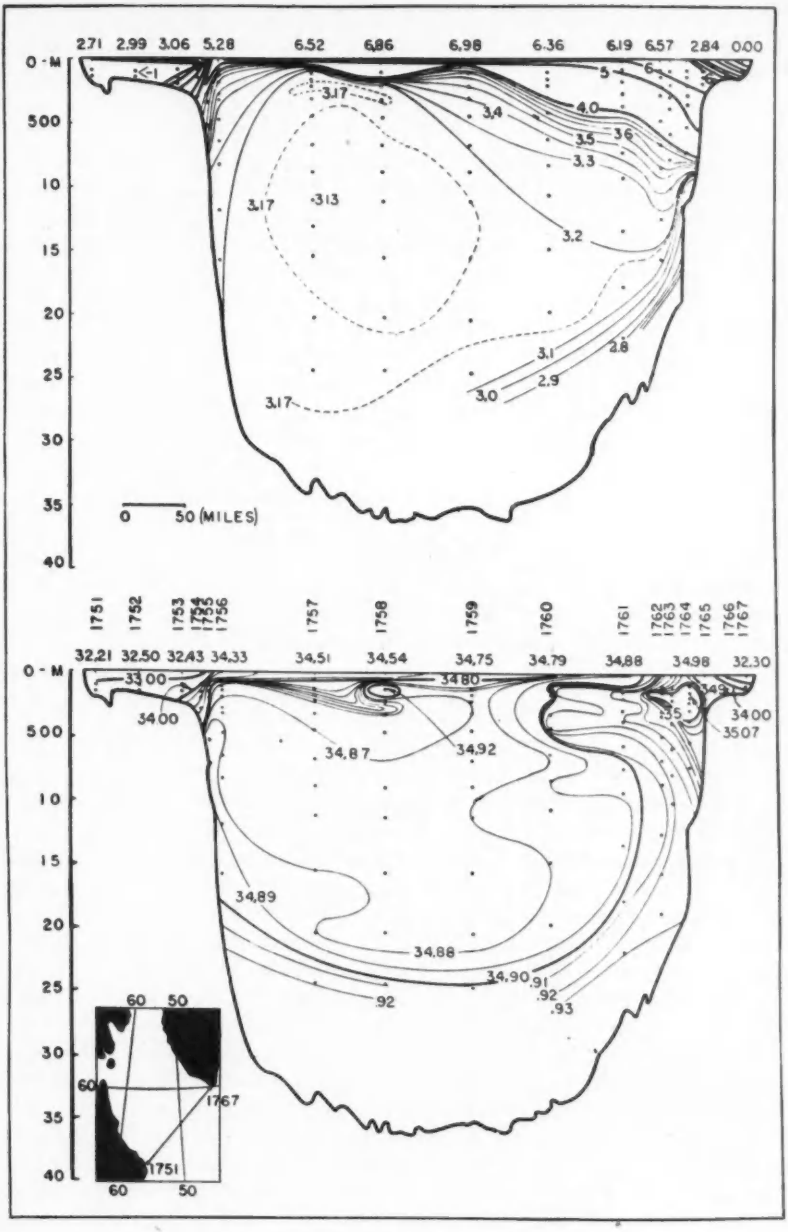


FIGURE 3. Temperature and salinity profile across the Labrador Sea. (From U.S. Coast Guard Bulletin 19, part 2.)

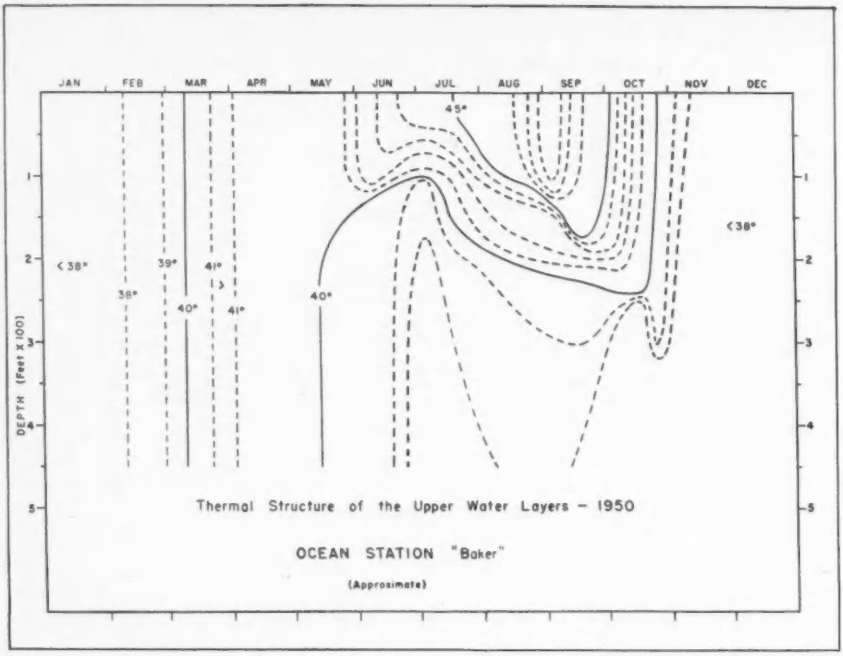


FIGURE 4. Thermal structure of upper water layers at Station "B", 1950.

section of the West Greenland Current, and it would be expected that the more boreal fauna might be contained therein.

Details of the thermal structure of the upper water layers vary so much with the meteorological agents, that only generalities will be considered in this section. It is known that the severe winter gales that prevail over the Labrador Sea have a profound effect upon the upper 100 metres of water. It is mainly because of the waves generated in these storms that the water becomes so thoroughly mixed that the thermocline essentially disappears, and it is also at this time that the cold air in contact with the surface absorbs the heat with the result that the surface becomes cold and dense, and overturns to further intensify the vertical turbulence. It is not until late spring or early summer that the thermocline appears (Figure 4).

Icebergs create a somewhat abnormal ecological influence when they appear in the central Labrador Sea because of both the melting of the fresh water (glacial) ice and the cooling of the sea water surrounding the iceberg as it melts. It might be expected that certain biological effects such as local phytoplankton blooms might appear in their vicinity, but according to Soule (1950) the effect of the iceberg is so very limited (perhaps less than 100 metres from the berg) that these phenomena, even if they existed, would be insignificant in the economy of the area. Furthermore, occurrence of icebergs in the central Sea is quite rare,

for they are essentially unaffected by wind stress and therefore remain within the current systems. Field ice, on the other hand, is grossly influenced by wind friction, and may proceed with considerable velocity, but the large surface areas exposed as compared to its mass render it subject to such rapid melting that floes are unknown in the central Sea.

Dissolved oxygen is rich throughout the Labrador Sea. Based upon the data gathered by the *Godthaab* (1928) and *General Greene* (1935), Smith (1937) has constructed oxygen profiles of the area that show values of dissolved oxygen of greater than 7.2 ml./l. in the surface layers and about 6.0 ml./l. at the bottom of the sea. No data are available to show the amounts of dissolved nutrients in the sea at the several seasons, but comparison of this region with comparable boreo-arctic areas would indicate that there is probably a winter maximum of phosphate, and a summer minimum (Sverdrup, Johnson and Fleming, 1946, p. 940). Until such data can be obtained by a continuous series of observations throughout the year at Station "B", it would be imprudent to speculate on dissolved nutrient-phytoplankton relationships, or upon the total productivity of the region.

THE INVESTIGATION

Object

It has been the purpose of this investigation to illustrate the seasonal fluctuation of the major constituents of the population of the open Labrador Sea and interpret the fluctuations detected. To this end, provisions were made to collect weekly samples at Ocean Station "B", analyse them quantitatively and qualitatively, and correlate changes of population with observed oceanographic and meteorological changes.

Table I. List of vessels occupying Ocean Station "B" during the investigation.

From	To	Vessel
25-II-50	18-III-50	USCGC *Castle Rock*
18-III-50	8-IV-50	USCGC *McCulloch*
8-IV-50	29-IV-50	HMCS *St. Stephen*
29-IV-50	20-V-50	USCGC *Duane*
20-V-50	10-VI-50	USCGC *Cook Inlet*
10-VI-50	1-VII-50	HMCS *St Stephen*
1-VII-50	22-VII-50	USCGC *Yakutat*
22-VII-50	12-VIII-50	USCGC *Coos Bay*
12-VIII-50	2-IX-50	USCGC *Spencer*
2-IX-50	23-IX-50	USCGC *Rockaway*
23-IX-50	14-X-50	USCGC *Chincoteague*
14-X-50	4-XI-50	USCGC *Dexter*
4-XI-50	25-XI-50	USCGC *Unimak*
25-XI-50	16-XII-50	USCGC *Matagorda*
16-XII-50	6-I-51	USCGC *Mackinac*
6-I-51	27-I-51	USCGC *Castle Rock*
27-I-51	17-II-51	USCGC *McCulloch*
17-II-51	10-III-51	USCGC *Yakutat*

Apparatus and Material

SHIPBOARD. By far the most expensive equipment in any oceanographic investigation is the collecting unit itself. In the present instance, no less than 14 different vessels were involved. Mainly, the type of ship used was the 311-ft. converted small seaplane tender (AVP), but there also were used two *Hamilton*-class 327-ft. cutters (WPG) and one Canadian frigate (PF) having a length of about 300 ft. The crews of these several vessels averaged about one hundred per ship, and the schedule required them to remain at their assigned Ocean Station for about 20-day periods. A list of the vessels is given in Table I.

Each ship was issued an equipment case holding nets, Nansen bottle, Clarke-Bumpus Sampler, formalin and spare gear, a sample case containing 24 pint Mason jars, and two 20-cm. Secchi discs, one black and one white. The bathythermograph was standard ship's equipment. Only three nets were used in this program: (*a*) a half-metre standard net with mesh of No. 2 silk bolting cloth, (*b*) a Clarke-Bumpus quantitative sampler using No. 2 and No. 12 silk bolting cloth nets. In addition, each unit was supplied with log sheets designed for this program.

The Clarke-Bumpus samplers were modified by leaving off the automatic opening and closing device, so that the net was in the open position at all times, a condition required for the oblique hauls to the surface. This was done in the interest of simplicity, and also for the reduction of malfunctions.

LABORATORY. In the laboratory the essential equipment consisted of dissecting and compound microscopes, a camera lucida and the usual laboratory accoutrements.

Method of Procedure

SHIPBOARD. At weekly intervals (weather permitting), the Ocean Station vessels took 20-minute oblique Clarke-Bumpus net hauls using No. 2 and No. 12 mesh nets from a depth of about 80 fathoms (150 metres) to the surface, with the vessel moving through the water at not more than two knots. The net was raised in short steps in order to sample the water column as evenly as possible. These observations together with white and black Secchi disc readings were made near local apparent noon.

At about the same time, a series of Nansen bottle samples were collected at depths of 0, 14, 27 and 55 fathoms (0, 25, 50 and 100 metres). A bathythermograph was used as the sounding weight of the Nansen bottle wire, and the resulting trace was used to check the depth of sampling. These Nansen bottle samples were immediately preserved in a 5 per cent formalin solution.

Later in the day, at least one hour after dark, a 20-minute half-metre net tow was made at the surface. All of these zooplankton samples were preserved in a 10 per cent formalin solution, and labelled uniformly. In connection with the night surface tow, observations were made of the amount and kinds of bioluminescence in the water.

Upon return to port each ship sent the preserved samples, log sheets and bathythermograms by express directly to the Narrangansett Marine Laboratory.

LABORATORY. On receipt of each set of samples and log sheets, laboratory personnel would immediately transfer the specimens to standard jars for permanent preservation, and forward the shipping containers to the next designated ship.

The half-metre net samples, identified by the symbol "T-1", were placed on a tripod ringstand and allowed to drain through No. 2 silk bolting cloth for a standard interval of 20 minutes. It was found later that this time interval could be reduced to about four or five minutes, and with more suitable results by scraping the underside of the draining net with a spatula to eliminate excess water. The damp sample was then carefully transferred with a histological section lifter into a graduated cylinder to which a measured volume of water had previously been added. The cylinders used were of the smallest size compatible with the size of the sample. In this manner the displacement volumes of samples were determined.

It was found that because of uncontrollable sampling errors, the half-metre net samples were accurate only for qualitative analysis. The displacement volumes (Figure 5) are presented only to indicate the gross signature of seasonal productivity.

Of the two remaining zooplankton samples, only the CB No. 2 was used in the counts. The CB No. 12 was retained for detailed reference to younger stages

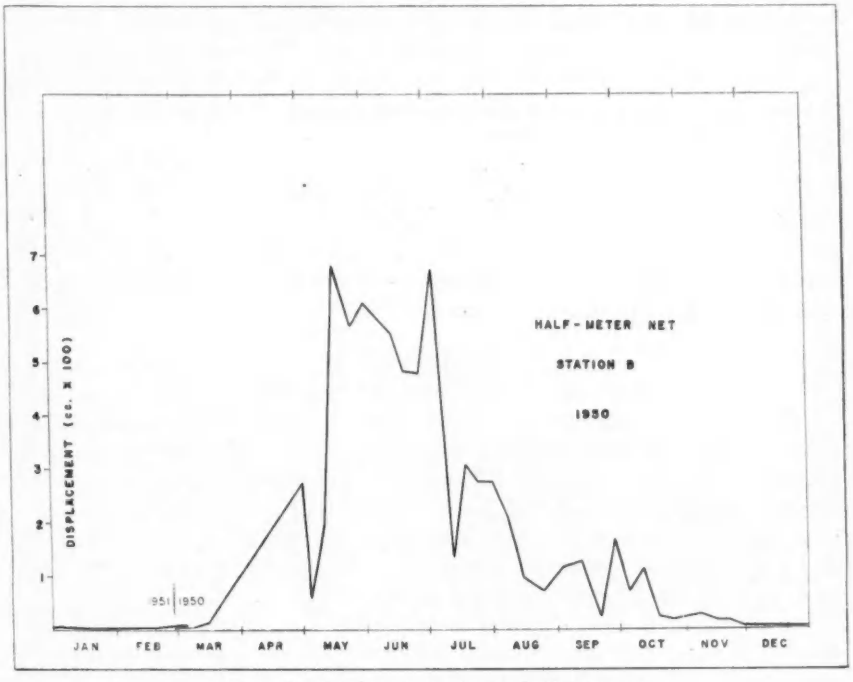


FIGURE 5. Displacement volumes, half-metre net.

and other small forms, and has been kept intact for future studies. The CB No. 2 samples were examined in their entirety and so far as possible every animal counted. If the sample proved too large for individual counts, the Stempel pipette was used to obtain aliquot portions, and the result adjusted to obtain the total number of animals. For the major species the absolute number of animals per cubic metre was computed, and the relative percentages were determined for all.

DISCUSSION OF RESULTS

Synopses of the Species

It must be recognized that the animals collected during this survey do not represent the total population under a given area of surface water, but rather are a particular segment of that population. Neritic influence is absent except for extremely rare traces in this area. Also, the vertical range of sampling did not extend to the zone occupied by the majority of the bathypelagic animals. Zooplankton forms a distinct intermediate portion of the ocean population. Present methods precluded collecting the minute and highly perishable naked flagellated cells on the one hand, and the larger nekton consisting of squid, fish and whales on the other. However, the important role played by these missing groups in the natural economy of any ocean area must be borne in mind.

The following synopses afford a background for a consideration of the seasonal and spacial distribution of the animals found. The copepod nomenclature has been taken from Jespersen (1940), and that for the euphausids from Einarsson (1945). For the remaining groups the latest nomenclature in general use has been utilized.

Comments on these species are based upon their occurrence at Station "B" during the present study. With but one year's records available it is not possible to state whether or not, biologically speaking, 1950 was a "normal" year in the Labrador Sea. Observations over a period of years would be required to establish this. Pending possible future meteorological or biological evidence to the contrary, it is assumed that reasonably average conditions prevailed.

Amphipods

Euthemisto bispinosa (Boeck) and *E. compressa* (Goës)

The author agrees with Stevensen (1924, p. 106) and Bigelow and Sears (1939, p. 299) that these animals are probably forms of the same species, even though the adults have minor distinguishing anatomical features and slightly different centres of seasonal distribution (Table II). It was noted that the eggs from the two forms were indistinguishable in size, shape and colour, and the young were likewise apparently identical. It is not until the animals are nearly adult that they may be readily distinguished.

The propensity of this animal for swarming at the surface is indicated by the sample of the night surface tow of September 21, 1950. At this time juveniles of *Euthemisto* comprised 66 per cent of the population, and the usually dominant *Calanus finmarchicus* only 25 per cent. The 150-0 metre haul showed no significant increase of *Euthemisto*. However, on this occasion the animal was found in

association with the intertidal alga *Ascophyllum*, which may have indicated that a small mass of coastal water favourable to the development of these animals had been transported into the area.

TABLE II. Seasonal occurrence of the species.

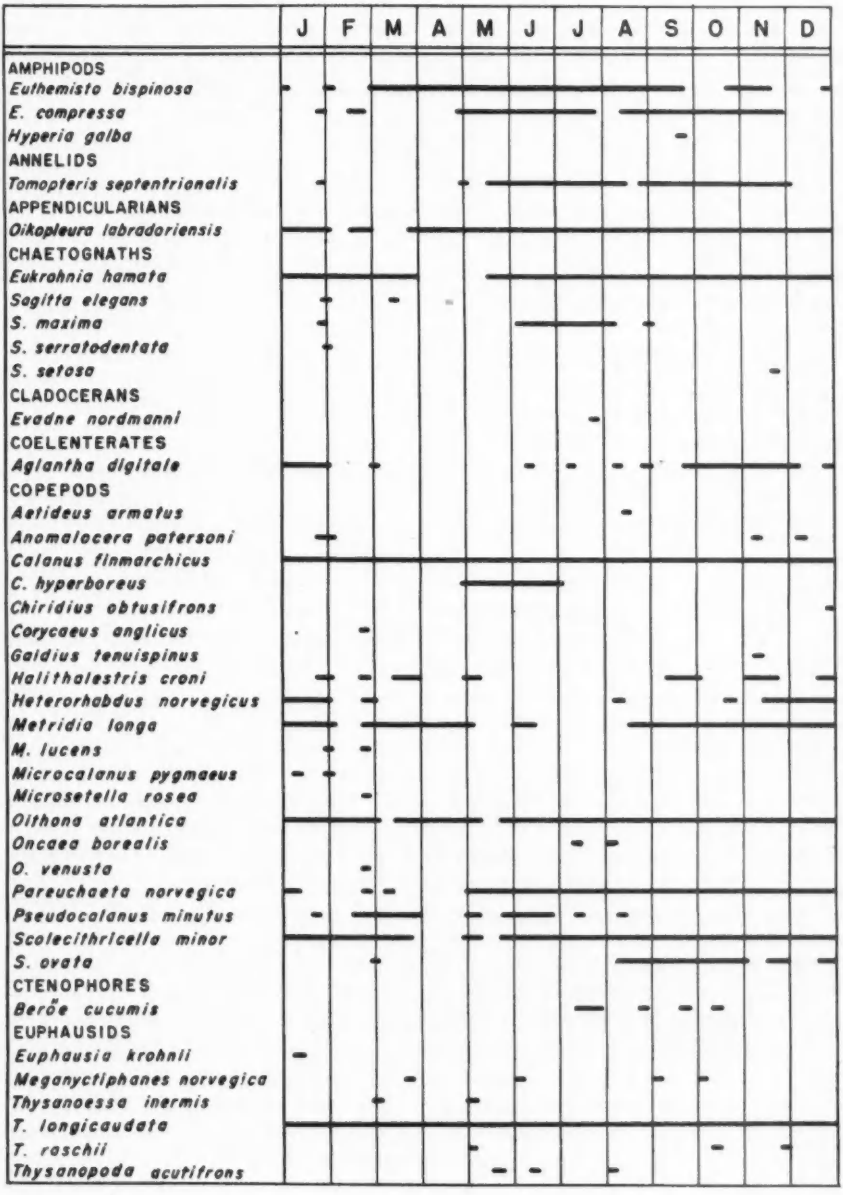
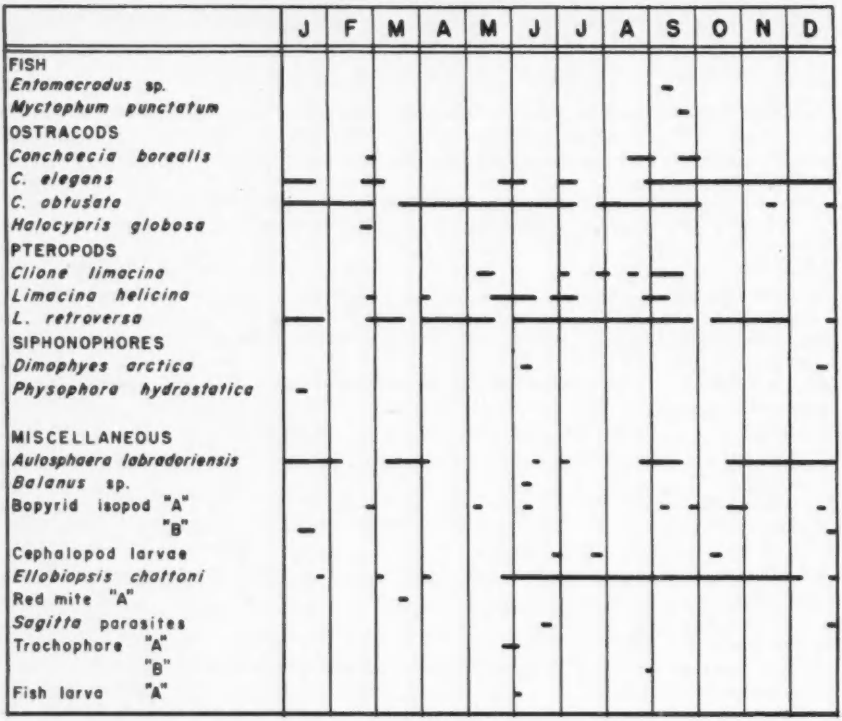


TABLE II (Continued)



This is the only species of amphipod of importance in the Labrador Sea region. It is decidedly indigenous in this locality.

Hyperia galba (Montagu)

The single appearance of four male specimens of *Hyperia galba* in the night surface sample of September 21, 1950 may have indicated that either *Aurelia* (Holmes, 1905) or *Cyanea* (Bigelow, 1926) medusae were in the immediate locality, for this amphipod is very frequently found commensal in those coelenterates. Although generally considered a boreo-arctic form, it has also been taken in quantity in the Mediterranean Sea (Stevensen, 1924). However, apparently it is never an important member of the boreal oceanic plankton.

Annelids

Tomopteris septentrionalis Quatrefages

The only important tomopterid found in 1950 in the Labrador Sea, *Tomopteris septentrionalis* is typically pelagic and is undoubtedly endemic in the region. According to Huntsman (1918, p. 90), this species should be the *only* tomopterid found in oceanic boreo-arctic waters, and from the present material this is apparently the case. Specimens were caught generally in night surface tows, both adults and juveniles occurring together throughout the year.

Although it is a bipolar species (Huntsman, 1918), there is evidence that this animal is normally boreal in the North Atlantic Ocean for Jespersen (1940, p. 36) reports it to be common south of Davis Strait but rare in Baffin Bay and north of Iceland.

Even though comparatively insignificant in percentage of the total population, *T. septentrionalis* probably exerts a noticeable effect in the economy of the region. Being a voracious predator, it preys on almost all of the other carnivores and herbivores of digestible size (Harvey, 1950, p. 117).

Appendicularians

Oikopleura labradoriensis Lohmann

Oikopleura labradoriensis is numerically one of the more important members of the plankton of the Labrador Sea. It occupies a peculiar ecological position in that it is adapted for feeding only upon the nannoplankton, and its presence in large numbers indicates a dense fauna (or flora) of these smaller organisms that escape the zooplankton nets.

Jespersen (1923, p. 144) found only *O. labradoriensis* in West Greenland waters, although Bückmann (1945) also lists *O. vanhoeffeni* and *Fritillaria borealis* from this general region. Although appendicularians usually arrive at the laboratory in rather poor condition owing to their fragile nature, all identifiable specimens in 1950 proved to be *O. labradoriensis*. *O. vanhoeffeni* is distinguished by its larger size and more neritic range. The absence of *Fritillaria* was more unexpected since conditions for its existence at Station "B" seem to have been favourable. It is unlikely that any were overlooked since its quite distinct body form would have made it readily detectable.

A point of discrepancy exists between the occurrence of *O. labradoriensis* in the present material and in Dr. Wulff's West Greenland collection. In the latter Jespersen (1923) found specimens only in subsurface hauls, and *never* in surface hauls. The present collection includes numerous specimens taken at the surface, and as all surface samplings were made at night, a diurnal migration is suggested.

Chaetognaths

Eukrohnia hamata (Möbius)

Eukrohnia hamata is the only important chaetognath in the offshore waters of the Labrador Sea. Although it rarely occurred as more than a few per cent of the population, it was almost always present in both the surface tows and the 150-0 metre hauls. This was reported as a very common, bipolar species (Fowler, 1906) that inhabits the upper water layers in the arctic, and the intermediate and lower water strata in the tropics. Jespersen (1923, p. 142) believes that temperature, rather than salinity, is the limiting ecological factor of its vertical distribution, but Bigelow (1926, p. 333) believes it to be somewhat stenohaline as well as stenothermal.

It should be noted that among all the hundreds of *E. hamata* examined from Station "B" not a single adult was found. Apparently the adults seek great depths in the boreo-arctic regions regardless of either temperature or salinity.

E. hamata being one of the most voracious of the planktonic carnivores, it was not uncommon to observe even very small juveniles with partly digested late copepodites and adults of *C. finmarchicus* either in their digestive tracts, or partly protruding from their jaws. Also, some were found to have as many as three copepods in their digestive tracts at the same time. For this reason it is assumed that *E. hamata* is of considerable importance in the economy of this region.

Because of the highly irregular appearance of early and late juveniles during the past year no estimate of the breeding seasons in the Labrador Sea can yet be made.

Sagitta elegans Verrill

In contrast to the preceding species, *Sagitta elegans* is generally found associated with the continental shelves, although in the arctic (Jespersen, 1923) it not uncommonly appears in very deep water. With such a distribution it is not surprising that only two specimens were obtained at Station "B", one in a 150-0 metre oblique haul on February 2, 1951, and one in a night surface tow on March 15, 1950. Although one of the more important members of the neritic boreal populations (Bigelow, 1926), only an occasional stray specimen of *S. elegans* reaches the central Labrador Sea, and in the present case might be indicative of either a rise from the depths, or horizontal transportation from neritic regions.

Sagitta maxima (Conant)

Sagitta maxima does not affect the economy of the surface waters of the Labrador Sea to any considerable extent, although of the Chaetognaths it is second in importance to *E. hamata*. The species is quite widely distributed, and Bigelow (1926, p. 326) found that only young specimens were obtained in the upper layers in the Gulf of Maine. Such appears to have been the case at Station "B" in 1950, for although some fairly large specimens were taken, there were no adults.

Sagitta serratodentata Krohn

A single specimen of *Sagitta serratodentata* was caught in a night surface tow on February 2, 1951. This represents very nearly the probable northwestern limit of its occurrence (Fowler, 1906, p. 72). Because it is a pronounced boreal form, its presence at Station "B" might be indicative of transport from more southerly regions.

Sagitta setosa J. Müller

According to Russell (1935, p. 324), *Sagitta setosa* is a more or less neritic species having a centre of geographical distribution in the southern North Sea and English Channel. He further states that this animal has never been recorded from the Western Atlantic.

A single specimen was found in the night surface tow of November 23, 1950. It was an adult, 20 mm. in length, having the typical distinguishing wedge-shaped seminal vesicles and fin arrangement (Russell, 1939). Although undoubtedly a stray immigrant, this specimen tends to indicate the presence of a water mass whose origin may have been the Shetland-Faroe area.

Cladocerans

Evadne nordmanni Lovén

The presence of several specimens of the neritic *Evadne nordmanni* in the 150-0 metre oblique haul of July 25, 1950 is somewhat difficult to explain. It is possible that they may have been driven seaward by the winds during their long resting stage, and although they had obviously survived under open ocean conditions for a time, it is improbable that they could become established in a high seas environment. The appearance of this animal is an uncommon phenomenon in oceanic regions.

Coelenterates

Aglantha digitale (O. F. Müller)

The early species of the normally oceanic Trachomedusae to be found at Station "B" was *Aglantha digitale*. It appeared as traces through the year except for April and May, when none was found. The greatest abundance in the Labrador Sea region appears to be in the late summer and early winter.

Bigelow (1926, p. 352) describes the species as being circumpolar and boreo-arctic. Inasmuch as specimens of all sizes were collected during the investigation, it would seem probable that *A. digitale* is endemic to the central regions of the Labrador Sea.

Copepods

Aetideus armatus (Boeck)

Jespersen (1940) reports *Aetideus armatus* to be quite cosmopolitan and common to all oceans except the Arctic Ocean. It is generally confined to deep water (Bigelow, 1926, p. 182), and is probably never an important component of the plankton. A single specimen was found in the 150-0 metre daylight haul on August 15, 1950.

Anomalocera patersoni Templeton

This strikingly beautiful deep blue copepod was found only as a trace form in 1950. Sars (1903, p. 140) describes its natural habitat as the surface of the open ocean, but remarks that great swarms have been found on occasions near shore. It is a summer visitor in the Gulf of Maine (Bigelow, 1926, p. 184) and Woods Hole regions (Fish, 1925, Fig. 46). At Station "B" it was found to be a strictly *winter* form in 1950-1951, occurring in traces from November to February. Both males and females were found, but only as adults. Because of its wide distribution, it cannot be used as an indicator species in this region.

Calanus finmarchicus (Gunnerus)

By far the most important of the zooplankton of the boreal regions, *Calanus finmarchicus* has been studied in detail both here and abroad. In the present investigation only limited interpretation of the observed evidence on the annual cycle of reproduction in this species has been possible because all collections were obtained in the surface layers at one location.

However, if one assumes that in the Labrador Sea *C. finmarchicus* is subject to the same controlling factors as have been observed elsewhere, augmentation

would be expected any time from early spring to midsummer depending on the rate of vernal warming of the water. In the Gulf of Maine (Fish, 1936), Clyde Sea (Nicholls, 1933) and the southern Norwegian area (Ruud, 1929) spawning starts in March or early April, and is followed by a succession of two or three generations depending on the thermal latitude. Farther north, in the boreo-arctic Norwegian Sea, Damas (1905) reported the principal propagation period to be in late June. East of Greenland in an arctic environment the season begins in late July (With, 1915). In the present instance the main augmentation season corresponds to that in the waters of the northern Norwegian Sea.

The increase of population in the middle of May to a value of 3740 animals per cubic metre (Figure 8) would hardly have been expected inasmuch as the adult-copepodite ratio did not vary appreciably at that time. In the absence of any significant horizontal drift, an ascent of adult animals from greater depths than those sampled would appear the most plausible explanation.

The abundance of *C. finmarchicus* decreased markedly at Station "B" during the winter months, at which time those found were mainly in the late copepodite stages. This agrees with observations made elsewhere by Bigelow (1926) and others. An unusually large percentage of males was found during the early spring months prior to augmentation. This agrees with observations by Clarke and Zinn (1937, Figure 5), and Damas (1905), who found males rare except immediately prior to vernal reproduction. All of this would seem to indicate that the copepodite males can withstand winter conditions more successfully than can the females, and thus the male percentage rises in the spring.

Figure 8 illustrates not only the definite major augmentation season of late July, but also the mortality of adults after maturation, and the very slow development of the succeeding generation during the following months. The indications are that after the first breeding period in early July the young develop rapidly for about two and one-half months, become adult and die without producing a significant second generation. Animals hatched in late July, near the middle of the main augmentation season, encounter low temperatures by the time that they reach late copepodite stages, and largely remain in those stages during the winter months. A few adults were found throughout the winter, but because of the extremely small stock in the upper layers during this period, their significance is uncertain. The few that survive the coldest months either rise from the depths in the spring or are transported into the area, and breed immediately following the diatom maximum. The data therefore give evidence of but one main annual generation of *C. finmarchicus* in northern boreo-arctic waters.

One of the surprising findings of the present investigation has been the comparative richness of the plankton, especially of *C. finmarchicus*, in an open ocean area. When one considers that in a single 20-minute surface tow with a half-metre net this species sometimes filled at least three quart jars, and that the Clarke-Bumpus sampler recorded up to 13,000 individuals per cubic metre of water, it would seem reasonable to assume that a very sizable population could be supported directly or indirectly by this animal alone. The capture of larval squid, fishes and fish larvae, as well as the reported presence of numerous "blackfish" whales in the area, afford further evidence of this.

Calanus hyperboreus Krøyer

This animal described by Sars (1903, p. 13) as a markedly polar form, was met with only in the late spring and early summer. It should be noted that no nauplii or young copepodites were found, but during the period of its presence (generally as traces) only late copepodites and adult females occurred. This would seem to indicate that this species is not indigenous in the area, but enters in late stages during the summer months with other subarctic forms. Essentially the same phenomenon was observed by Bigelow (1926, p. 218), and Fish and Johnson (1937) in the Gulf of Maine. There are indications that the animal occurs during the influx of cold, northern waters sometimes as far south as the Chesapeake Capes (Bigelow and Sears, 1939).

C. hyperboreus was at no time an important member of the plankton of the upper water layers in this area.

Chiridius obtusifrons G. O. Sars

A decidedly boreo-arctic species, this copepod ranges from the arctic ice, where it may be found at the surface (Sars, 1900) to the American coast off Nova Scotia (Bigelow, 1926). Jespersen (1940, p. 19) found it limited to intermediate depths (600-800 metres wire) near Iceland. The only occurrence in the present material, on December 31, 1950, was in the 150-0 metre daylight haul.

Corycaeus anglicus? Lubbock

This curious little cyclopoid was found in a night surface tow on February 25, 1951. Because it was not wished to damage the only specimen by dissection, conclusive identification was not obtained and the species designation is indicated as tentative.

Sars (1918, p. 197) describes its distribution as the North Atlantic Ocean, and considers it to be markedly pelagic. Jespersen (1923, 1940) failed to find it in West Greenland or Iceland waters, and an occurrence in the Woods Hole region has been attributed to transport from subtropical waters (Wilson, 1932). It would therefore appear that in the Labrador Sea *C. anglicus* is an indicator species of subtropical water.

Gaidius tenuispinus (G. O. Sars)

A single specimen of this copepod was found in the night surface tow of November 10, 1950. Sars (1900) refers to it as a typical boreo-arctic form ranging as far north as 85° where it has been found under the ice. Like numerous other bipolar forms (Jespersen, 1940, p. 19) it extends into mid-latitudes, but only at considerable depths (Bigelow, 1926, p. 238).

Halithalestris croni (Krøyer)

Although almost always a trace form, this large harpacticoid occurred throughout the year at Station "B" except in June, July and August. Ripe females were taken only in March of 1950. It is therefore assumed that the principal augmentation season for this animal in boreal waters is early spring. Near Iceland it sometimes enters coastal waters (Jespersen, 1940), but elsewhere it appears to be markedly pelagic (Sars, 1911) and generally remains near or at the surface (Wilson, 1932).

Heterorhabdus norvegicus (Boeck)

According to Sars (1900, p. 79), *Heterorhabdus norvegicus* is a typical calanoid of the polar basin. It occurred as a trace form at Station "B" throughout the year except in spring and early summer months. It was found to be bathypelagic in the open ocean by Sars (1903, p. 120), although Jespersen (1940) reported it eurypelagic, but only *over* deep water, and never within Iceland fjords. In the Labrador Sea it appears commonly as a surface form.

Jespersen (1939, p. 33) reported that *H. norvegicus* presumably spawned in July and August in East Greenland waters. The only ripe females that were observed in the present material occurred in October and November, 1950, with some juveniles also being found in the latter month. It may be that the effect of coastal warming or other factors permits slightly earlier breeding seasons inshore than in the open sea.

Metridia longa (Lubbock)

This brilliantly luminescent copepod occurred at Station "B" throughout the greater part of the year in 1950, with a seasonal maximum in the winter months. Volumetrically it proved insignificant in the plankton. The capture of many juveniles at the surface on about the first of March, 1951, would indicate that this species is probably a midwinter breeding form indigeneous to the area. Although Jespersen (1940) defines its occurrence as only over great depths, and Sars (1903), too, found it common mainly over deep water, Bigelow (1926), and Fish (1936) devote considerable discussion to its habits in the Gulf of Maine and other comparatively shoal areas.

There is no direct evidence that this species is responsible for a significant proportion of the bioluminescence observed at Station "B" during the course of this study. Comparison of the relative concentration (Figure 7) and the bioluminescence signature (Figure 13) indicates that the juveniles, at least, of *M. longa* do not exhibit measureable bioluminescence.

Metridia lucens Boeck

Metridia lucens, which appeared only as minor traces at Station "B" in late January, 1951, is a much more southerly ranging form than *M. longa*. In this area it is undoubtedly an infrequent migrant, probably from a Greenland or Labrador coastal habitat. It is also possible that these specimens originated in south boreal oceanic waters. Jespersen (1940) reports it to be generally boreal, while Bigelow (1939) observes that the center of its concentration lies fairly near the edge of the continental shelves.

Although this species is known to be quite luminescent, it is so rare in this area that its importance in this respect is negligible.

Microcalanus pygmaeus (G. O. Sars)

This remarkably small copepod, which was found in small numbers at Station "B", and only in January, 1951, is reported to be a surface form in the arctic, and bathypelagic in more southerly latitudes (Jespersen, 1940). Sars (1903, p. 157) describes it as a true deep water form. This probable deep water origin would explain its occurrence at the surface in the Labrador Sea in winter when temperature conditions were favourable for it.

Microsetella rosea (Dana)

A single, well-preserved specimen of *Microsetella rosea*, 0.6 mm. in length, was taken on February 17, 1951, in a 150-0 metre daylight haul. This species is strikingly different in size, colour and in length of caudal setae from *M. norvegica*, the only other member of the genus. Neither Sars (1911) nor Jespersen (1923, 1940) list this copepod in the boreo-arctic fauna of Norway, West Greenland or Iceland. It also is absent in the records of Bigelow (1926) and Fish and Johnson (1927) from the boreal waters of the Gulf of Maine. However, farther south Fish (1925, p. 142) found it in considerable numbers among late summer Gulf Stream forms in temperate Block Island waters in 1922-1923. It would thus appear that *M. rosea* is a warm water animal, and one of the better subtropical indicator species. Its presence in the central Labrador Sea in the coldest part of winter can only indicate an influx of this water at that time.

Oithona atlantica Farran

Oithona atlantica is one of the most important copepods of the Labrador Sea region. It was found continuously at Station "B" in 1950 except for occasional breaks in the spring-time. Sars (1918, p. 7) and Wilson (1932, p. 315) describe it to be markedly pelagic as compared to the more neritic *O. similis*. Rosendorn (1917, p. 13) believes that *O. atlantica* is frequently confused with *O. plumifera*, but in view of the tropical and subtropical distribution of the latter it is improbable that any *O. plumifera* would have occurred in the samples except perhaps in winter as readily identifiable adults. No such instance was detected in 1950.

Jespersen (1940, p. 90) observed egg-bearing females in June and July in the waters near southern Iceland, and therefore assumed that the breeding season coincided with the warming of the water. In the present material egg-bearing females were found from June throughout the remainder of the summer and fall. Then, following a slight increase in the number of ripe females in early December, an abundance of nauplii and copepodites appeared in late December and lasted until February, 1951 (Figure 9). During the latter months *O. atlantica* formed about one-third of the total population. It is not known whether this is a normal situation.

There is excellent evidence that *O. atlantica* is a subsurface form which does not rise to the surface at night except in comparatively small numbers (see Figure 6). Comparison of the relative numbers between the half metre net (T-1) night surface tows and the 150-0 metre Clarke-Bumpus (CB-2) daylight hauls illustrate this well. Apparently the greater part of even the juveniles remains below the uppermost layers at all times.

Oncaea borealis G. O. Sars

Considered by Jespersen (1928, 1940) as much more of an arctic species than boreal, *Oncaea borealis* may be used with some confidence as an indicator of arctic waters. A single specimen of this cyclopoid was taken in the night surface tow of July 12, 1950, and its occurrence on that date is further evidence of the possible influx of arctic waters into the area at that time.

Oncaea venusta? Philippi

A single male specimen, 0.90 mm. in length, was taken in the night surface tow of February 25, 1951. Wilson (1932, p. 354) lists this species as subtropical-boreal, as do Bigelow and Sears (1939, p. 334). It is not listed in the fauna of Norway by Sars (1918) or in Iceland waters (Jespersen, 1940).

The present specimen agrees with published descriptions of *Oncaea venusta*, and can be readily distinguished from *O. borealis* and *O. similis*. The species designation is indicated as doubtful, however, because of the inadvisability of destroying the only specimen. It would appear that here again is a form indicative of an influx of subtropical waters found in the central Labrador Sea in the middle of winter, but at no other time.

Pareuchaeta norvegica (Boeck)

Pareuchaeta norvegica is a quite common, but not important, form at Station "B". It is found generally throughout the year except from the late winter to the early spring. Ripe females were found from May to December, 1950, and juveniles were observed from May, 1950, to January, 1951.

It should be noted that no adult males were found at Station "B" in 1950. It must be assumed that males inhabit depths below those sampled in this area, and the absence of eggs and nauplii suggests that the breeding, if it occurs in the area at all, takes place at considerable depths.

Pseudocalanus minutus (Krøyer)

Pseudocalanus minutus formed no significant proportion of the population at Station "B" in 1950, but was found to have its maximum abundance from the early spring to the early summer months. Wilson (1923, p. 44) describes it as a boreo-arctic animal, and Jespersen (1940, p. 15) indicates that it is somewhat neritic, but may be found almost anywhere in boreal or arctic waters. In view of this wide distribution, and because of its minute size and relatively small numbers, *P. minutus* assumes no special importance in the economy of the region, or as an indicator animal. The present data do not allow an estimate of the breeding season in this area.

Scolecithricella minor (Brady)

Scolecithricella minor assumed considerable numerical importance in the Labrador Sea in 1950. Ordinarily this animal is listed as an epiplanktonic, pelagic form of wide boreo-arctic range with great tolerances for variations of temperature and salinity (Sars, 1903), but nowhere is it listed as quantitatively significant. Bigelow (1926, p. 286) indicates that it is to some extent a warm-water animal, but Jespersen (1939, p. 22) shows that it is equally at home in the northern Greenland Sea, although not north of Davis Strait in the western Atlantic.

During the present investigation, *S. minor* was numerically one of the few animals to assume a significant percentage of the population, especially in the mid-winter night surface hauls, attaining a value of 44 per cent at one December observation. The breeding season appears to be from August to December. This animal possibly furnishes food for the larger copepodites of *C. finmarchicus*, although there is no direct evidence of this.

Scolecithricella ovata (Farran)

According to Jespersen (1940, p. 41), *Scolecithricella ovata* is to a far greater degree an Atlantic boreal form than is *S. minor*. It appeared as traces mainly in the fall of 1950 at Station "B". Because of the paucity of specimens, no information is available as to the breeding season.

Ctenophores

? *Beröe cucumis* Fabricus

Occasional specimens of a ctenophore, tentatively identified as *Beröe cucumis*, were obtained in the late summer and fall of 1950 at Station "B". All specimens were in quite poor condition when inspected, but *B. cucumis* is well known in this area, and is typically pelagic (Jespersen, 1940a).

Inasmuch as this ctenophore is known to emit bioluminescence, it would attain some importance in this respect should it swarm in the area, and in view of its known voracity (Bigelow, 1926) could have considerable effect upon the economy of the area at those times.

Euphausids

Euphausia krohnii (Brandt)

According to Einarsson (1945, p. 128), *Euphausia krohnii* is a decidedly warm-water form whose northern limit of spawning approximately follows the mean annual isotherm for 10°C. in 100-metre depth. However, in the night surface tow of January 13, 1951, three adults of this animal were found, which again tends to indicate an influx of boreal-subtropical water into the area at this time. Except as an indicator species, *E. krohnii* is unimportant in the area.

Meganyctiphanes norvegica (M. Sars)

Meganyctiphanes norvegica is known not only from the North Atlantic Ocean, but also from the Mediterranean Sea. It was found occasionally at Station "B" from early spring until fall in 1950. Einarsson (1945, p. 112) indicates that adults are generally found in deeper strata than are the juveniles, but both adults and juveniles were taken near the surface at Station "B" in 1950. The youngest specimen was a calyptopis I stage taken in the 150-0 metre haul of May 31, 1950, and the largest one, 40 mm. in length, was taken on October 5, 1950, in a night surface tow. As far as is known, these are the first records of *M. norvegica* from the central Labrador Sea, but its presence here was not unexpected.

Thysanoessa inermis (Krøyer)

This species was found only as traces in the late winter and early spring at Station "B". One large male specimen, 23 mm. in length, was taken with three small ones from the night surface tow of February 28, 1950, and a single specimen 22 mm. long was secured by the same method on May 4, 1950. According to Einarsson (1945, p. 146) these large individuals are probably second-time spawners. No juveniles were found nor were any expected in view of the tendency of this species to spawn over coastal banks (Einarsson, 1945, p. 122).

Thysanoessa longicaudata (Krøyer)

By far the most important of all the euphausids at Station "B" is *Thysanoessa longicaudata*. It is one of the few year-round forms, and occasionally forms the main bulk of the population, especially in the winter. Einarsson (1945, p. 119) indicates that, unlike the preceding species, *T. longicaudata* is strictly oceanic in breeding habits, and is almost exclusively a boreo-arctic Atlantic Ocean animal.

There has been some disagreement concerning the vertical distribution of the species (Einarsson, 1945, p. 120), but from the evidence established by the present investigation (Figure 6) there can be little doubt that this animal should be considered primarily a subsurface rather than a surface form, although many specimens were taken at the surface.

The breeding season in the Labrador Sea starts about the first of May, and continues through September, the greatest augmentation occurring in July and August (Figure 10). During the winter months only adults were found.

T. longicaudata must play an important role in the biology of the region not only because of the readily available food that it must consume during the summer augmentation season, but also for the food that it must supply for the larger organisms throughout the year.

Thysanoessa raschii (M. Sars)

Young adults of *Thysanoessa raschii*, up to 19 mm. in length, occurred as traces in night surface tows in late spring, and again in the fall of 1950. Both Einarsson (1945, p. 126) and Bigelow (1926, p. 145) agree that this species is primarily a coastal form with but few exceptions. It is believed that the present material offers some evidence that this animal is perhaps more pelagic than previously assumed, and that when away from its normal coastal habitat does not necessarily seek the greater depths.

Thysanopoda acutifrons Holt and Tattersall

Only the younger juveniles of this species were found at Station "B" in 1950, and these were present only in traces from May until August. It should be noted that except for one doubtful specimen, all of the animals were taken in the night surface tows rather than in the 150-0 metre daytime hauls. Einarsson (1945, p. 106) indicates that this form is quite bathypelagic, especially in the larval stages, but the present data, admittedly inadequate, do not seem to bear this out.

One specimen, believed to be the first record of the calyptopis I stage of this species, and about 1.2 mm. long, was taken in the night surface tow of May 25, 1950. It occurred among colyptopis III larvae of *T. longicaudata*, and calyptopis III and furcilia III juveniles of *Thysanopoda acutifrons*.

Fishes

? *Entomacrodus* sp.

A single specimen of 22 mm. total length, was taken in the night surface tow of September 12, 1950, at Station "B". Except for its larger size, this fish resembles in many particulars one of the species of *Entomacrodus* as figured by

Garman (1899, Plate L, Figure 1). Inasmuch as this is not a planktonic form, further taxonomic evaluation is being withheld until a later date.

Myctophum punctatum Rafinesque

A very large (90 mm.) adult specimen of *Myctophum punctatum* was taken in the night surface tow with the half-metre net at Station "B" on September 21, 1950.

Although the capture of this fish was quite accidental, its very presence in this open ocean region indicates the possible existence of a sizable fish population underlying the surface waters of the open boreal seas. Goode and Bean (1895, p. 72) cite many examples of the species being washed aboard Grand Banks schooners, and they also mention specimens taken by the ship *Fish Hawk* in depths of water ranging to about 1000 metres, but no reference can be located that records *M. punctatum* as far offshore as Ocean Station "B".

Ostracods

Conchoecia borealis? Sars

All of the specimens of this animal taken at Station "B" in 1950 were juvenile, quite difficult to distinguish from *C. elegans* of the same size, and therefore the species designation is indicated as being doubtful. According to Klie (1944, p. 4) this is an Atlantic boreal and subarctic form. Sars (1928, p. 28) lists its western Atlantic distribution as in Labrador Current and in the Arctic Ocean, while Jespersen (1923, p. 133) found it only from Lille Karajakfjord. Jespersen also states that *Conchoecia borealis* is essentially a bathypelagic species in its normal subarctic habitat, but to the southward it is found nearer the surface.

Apparently it is not important in the plankton of the Labrador Sea.

Conchoecia elegans Sars

Klie (1944, p. 4) lists this ostracod as being eurythermal, euryhaline and eurybathic, although Jespersen (1923) and Sars (1928) find that it favors boreo-arctic waters at mid-depths.

The breeding season in the Labrador Sea appears to be quite long, from August through November, and numerous young were collected from August through January. It occurred irregularly throughout the year at Station "B", but never became a significant member of the population.

Conchoecia obtusata Sars

In contrast to the preceding species, *Conchoecia obtusata* is numerically strong in the Labrador Sea plankton, especially in the spring. Owing to the paucity of data concerning this animal in the coastal waters of Norway (Sars, 1928) and West Greenland (Jespersen, 1923), and its known occurrence in the open Atlantic (Klie, 1944), it must be concluded that this species is the most pelagic of the ostracods represented in the collections. It is certainly indigenous in the Labrador Sea, for all stages of development were found, and in considerable numbers. The breeding season in 1950 in this region extended from about the last of May until the first of October, and the majority of the juveniles appeared from January to March.

Halocypris globosa? (Claus)

A single specimen, taken in the night surface tow of February 25, 1951, appears to be *Halocypris globosa*. Little is known of its northern distribution, and it is not listed by Sars (1928) in the fauna of Norway, nor did Jespersen (1923) find it along the west coast of Greenland. Klie (1944, p. 4) lists it as a trace form in the Faroe-Iceland area and west of Ireland. In this case it must be considered as a boreal animal carried well westward of its normal eastern Atlantic habitat.

Pteropods

Clione limacina (Phipps)

Clione limacina occurred in traces throughout the summer from May through September, 1950, at Station "B". Bigelow (1926, p. 125) considers it to be a typical oceanic, boreo-arctic animal. Jespersen (1940a, p. 63) reports that it was taken only over deep water in May in the Iceland area, but by August it occurred there even within the fjords. In western Greenland waters he (1923, p. 127) found propagation occurring in mid-summer. Because of its wide distribution, this species cannot be considered a good indicator form in the Labrador Sea area, but its occurrence suggests the presence of arctic waters rather than boreal in the summer.

Limacina helicina? (Phipps)

Only juveniles, which may easily be confused with the young of *L. retroversa*, were found at Station "B" in 1950. Therefore, the species designation is declared doubtful. Tesch (1947, p. 3) reports that *Limacina helicina* is a typically arctic animal inhabiting the colder waters of Spitsbergen, north of Iceland and Davis Strait, as well as the Labrador Current. Jespersen (1923, p. 138) found that it occurred most abundantly in waters of $-0.51°$C. to $-0.73°$C., and Bigelow (1926, p. 59) considered it an excellent indicator of water of arctic origin. Because of the uncertainty of identification, it would be imprudent to speculate on the occurrence of *L. helicina* in the Labrador Sea.

Limacina retroversa (Fleming)

This typically boreal pteropod (Tesch, 1947) is a year-round inhabitant of the central Labrador Sea. Bigelow and Sears (1939, p. 279) record its presence as far south as 36°N. along the American coast, and Tesch (1947, p. 5) reports its northern limits as Davis Strait in the western Atlantic, and Spitsbergen in the eastern Atlantic. Jespersen (1923, p. 137) failed to find it in the colder waters of West Greenland.

From the present material it is difficult to assign any definite breeding season, for both adults and juveniles were found throughout the year, and in no significant differences of proportion. It is certain that this pteropod is indigenous in the region, and thus probably plays an important part as the food of other pelagic animals.

Siphonophores

Dimophyes arctica (Chun)

Dimophyes (= *Diphyes*) *arctica* was at first thought to be an arctic species, and was so described by Bigelow (1911, p. 369), but later investigations (Bigelow

and Sears, 1939, p. 131) have shown that it is a cosmopolitan, bipolar form having a centre of abundance in waters of less than 10°C. in the arctic, and less than 2°C. in the antarctic.

Specimens were found at Station "B" in June, and again in December, 1950. From the vertical distribution described by Bigelow (1911, p. 379) it would seem probable that this species is more abundant in the bathypelagic regions of the Labrador Sea than at the surface.

Physophora hydrostatica Forskål

A single, fragmented specimen of this species was found at Station "B" in the night surface tow of January 13, 1951. The sample contained the stem, nectophores and pneumatophores. Although Jespersen (1923) failed to find it in Dr. Wulff's West Greenland collection, he reported it (1940a, p. 23) as common in Icelandic waters. Bigelow (1911, p. 371) describes it as being neither an arctic nor a tropical form, and observed that it was not found in waters colder than about 45°F. In the present instance, where the water temperature was about 38°F., it would seem that the animal can withstand temperatures much lower than previously supposed.

Miscellaneous

Balanus sp.

One of the anomalies in the present collection was a cyprid larva in the CB-2 daylight sample of June 7, 1950. It is believed that it came from an adult barnacle attached to the ship's hull, for its location precludes the possibility of drift from the distant shore.

Cephalopod larvae

Three squid larvae, believed to be of the same species, were taken in three night surface tows on June 27, July 19 and October 12, 1950. Their occurrence is indicative of a possibly large nektonic population inhabiting the lower strata of water in the Labrador Sea. The author has observed schools of adult squid in this general region on previous occasions.

Relative Numbers

It is perfectly possible to obtain good estimates of comparative richness of plankton in various areas or at several seasons by means of towing qualitative nets over measured traverses and calculating net filtering efficiency. This has been done by many previous investigators. But in the present instance the errors occasioned by towing from a drifting ship in open waters precluded such estimates, and therefore the half-metre net was used only for purely qualitative collections.

Figure 6 is a relative representation of the population and is based on the weekly sample analyses, but for both the CB-2 and T-1 tows. Here it should be noted that the deeper hauls show much greater variation of composition than do the night surface tows, but that the T-1 tows generally reflect the composition of the underlying population. The strong variations from December to March are due in part to the reduced population density during that period, so that an

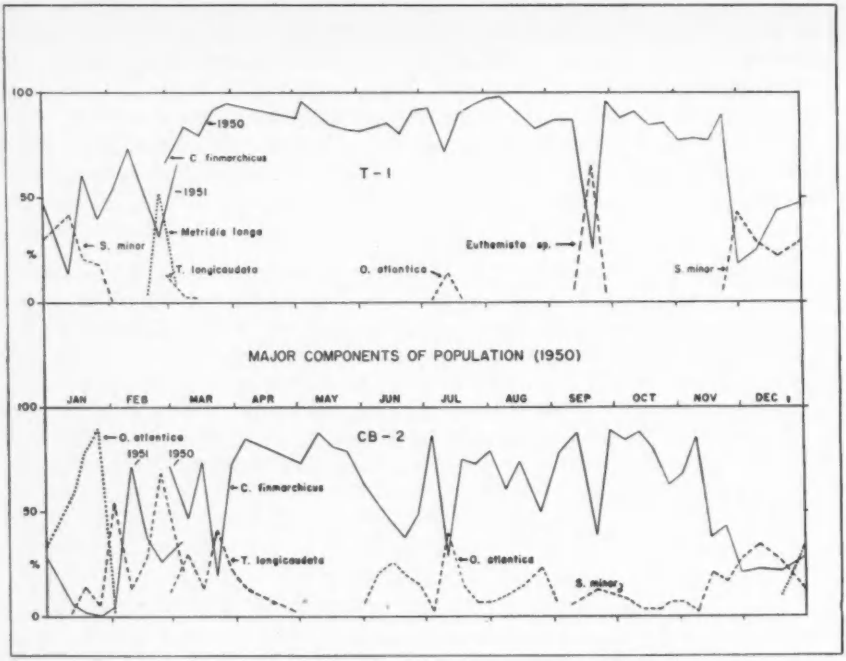


FIGURE 6. Major components of population, 1950.

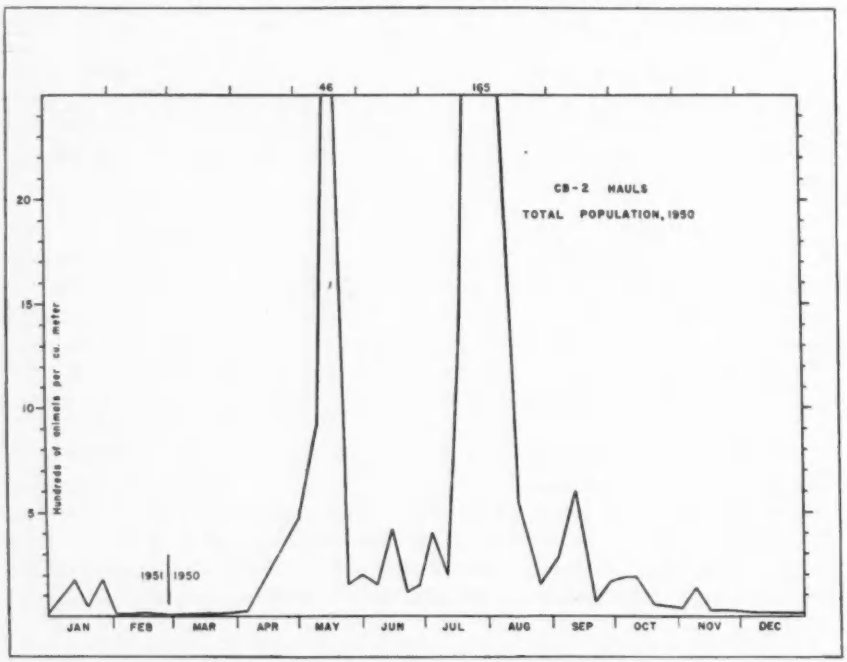


FIGURE 7. Absolute numbers of total population.

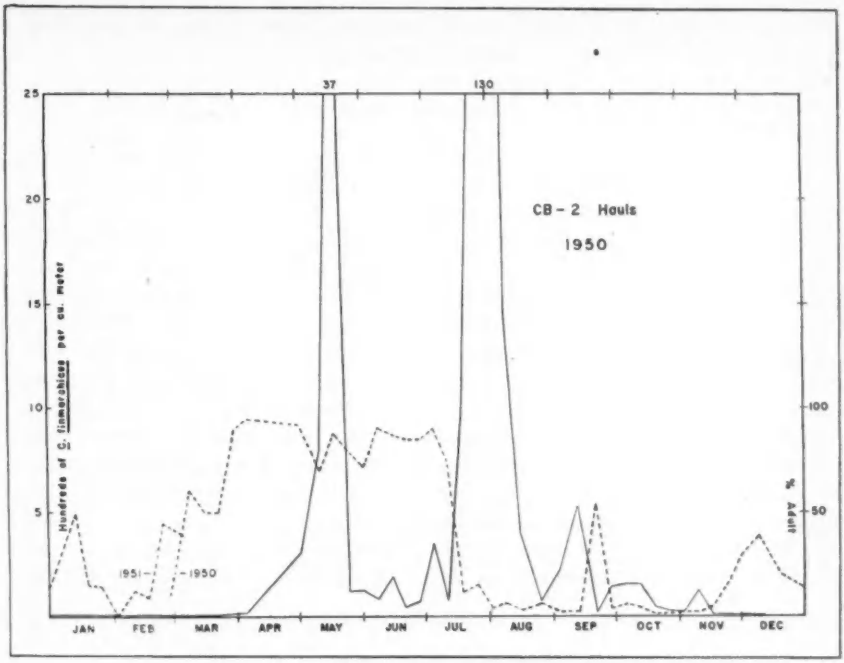


FIGURE 8. Absolute numbers of *Calanus finmarchicus*.

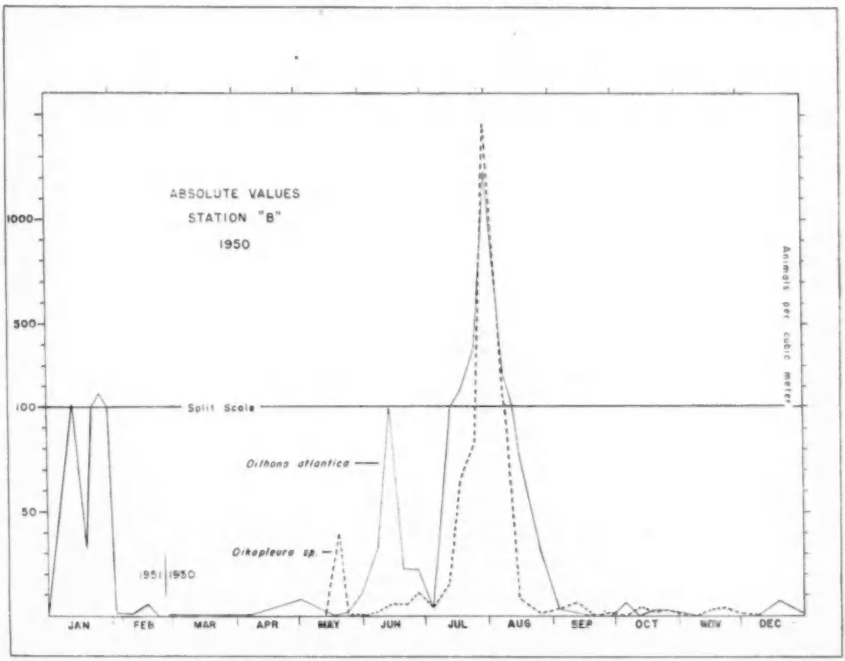


FIGURE 9. Absolute values, Station "B", 1950.

increase or decrease of but a few specimens alters the relative proportions radically. Both graphs illustrate the great importance of *C. finmarchicus* in this region and the spotty and irregular appearance of the remainder of the species.

Absolute Numbers

From the Clarke-Bumpus sampler using No. 2 mesh silk, the absolute numbers of animals per cubic metre were determined for the more important constituents of the population in the 150-0 metre water column. It was necessarily assumed that all of the samplers issued to the collecting vessels had a standard metreing value of 4.0 litres of water filtered per revolution of the rotating vane (Clarke and Bumpus, 1940). Subsequent tests indicate that this value may be in error as much as 20 per cent owing to constructive variations, damage to vanes, or improper lubrication. Inasmuch as it was impractical to recall the many instruments for recalibration at frequent intervals, the mean value of 4.0 was used, and care must therefore be exercised to allow for the probable inaccuracies.

The signature of the numerical population (Figure 7) shows the marked variation observed throughout the year. Comparison of this graph with that of *C. finmarchicus* alone (Figure 8) illustrates again the great importance of this copepod, for the signatures are essentially similar.

It is possible that jamming of the vanes with seaweed, spinning of the vanes in the wind, or other malfunctions of the Clarke-Bumpus sampler would result

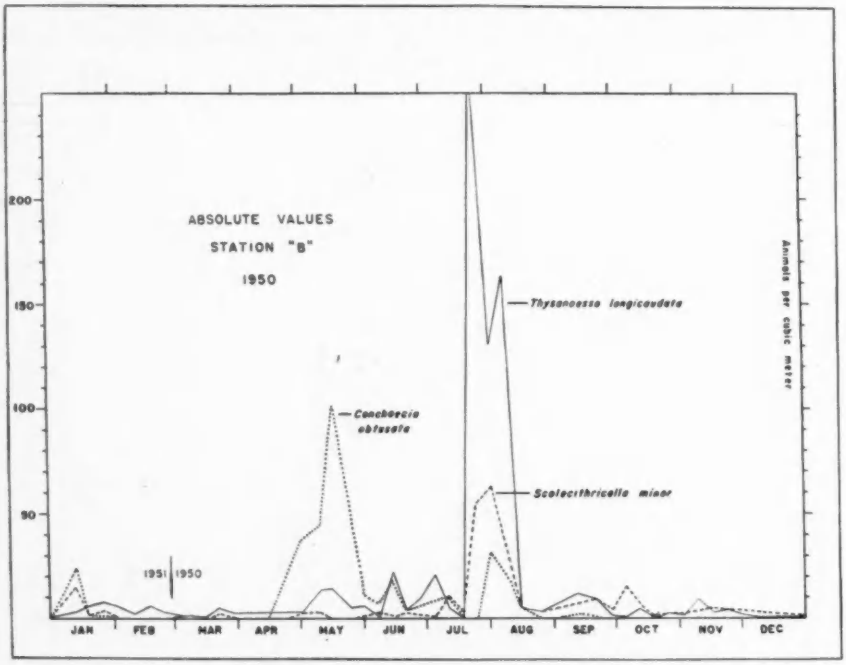


Figure 10. Absolute values, Station "B", 1950.

in false reading, and therefore inaccurate results. But there is evidence that such errors did not occur in any appreciable extent during the present investigation for two reasons: (*a*) peaks of population for the individual species are generally separated, even in the great augmentation season, and (*b*) the major increases of the numerical population are always preceded and followed by definite trends over a period of at least several weeks.

Transparency

The Secchi disc method of determining the transparency of the water was utilized at every daytime plankton station. The Ocean Station personnel lowered the disc on the shaded side of the vessel to the point of no visibility, and recorded that depth as the transparency. A black disc 20 cm. in diameter was to have been used as well as the usual white 20 cm. disc, but only few of these black disc lowerings were made owing to misunderstanding of instructions.

According to Clarke (1942, p. 229), the white Secchi disc of 20 cm. diameter shows general good agreement with photronic photometer measurements where the relationship $k = 1.7/D$ is employed. Here, "k" represents the extinction

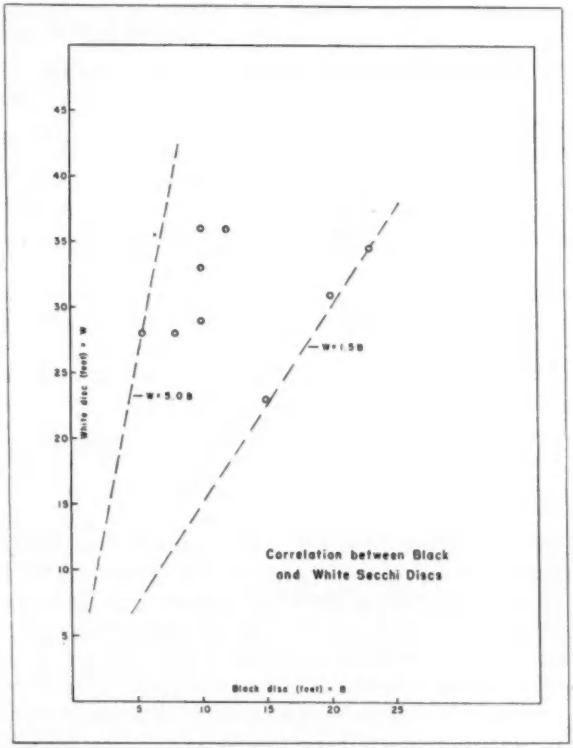


FIGURE 11. Correlation between black and white Secchi discs.

coefficient, and "D" the depth in metres at which the Secchi disc is lost from sight. The extinction coefficient "k" may be considered to mean approximately the percentage reduction of light intensity per metre of immersion. Thus a "k" value of 0.150 would mean that the vertical submarine illumination is reduced about 15 per cent per metre (Clarke, 1939).

The "surface loss" of transparency in the upper few metres of water (Clarke, 1942) cannot be measured by the Secchi disc method, but inasmuch as the sea surface is almost never glassy smooth in the region of Station "B", it is assumed that these surface effects are at least roughly equal for all observations, thus making the disc observations comparable.

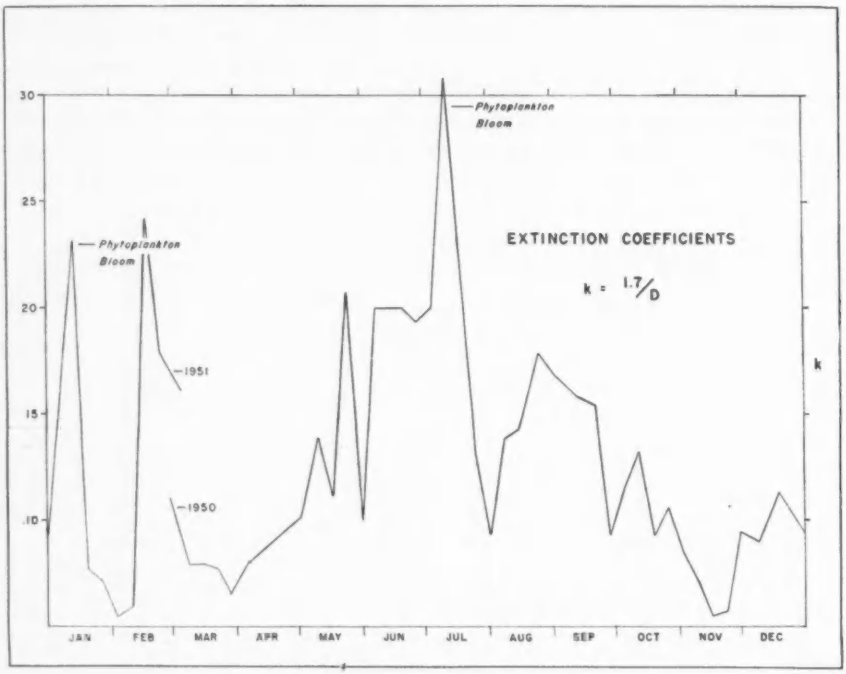


FIGURE 12. Extinction coefficients.

From the few simultaneous observations with the black and white discs it was found that no definite relationship existed between them that would allow determination of a factor to convert black disc visibility to the extinction coefficient, k. The plot of the white disc visibility as compared to black disc visibility (Figure 11) illustrates the great variability of ratios.

The most important result of this phase of the investigation was the finding of tremendous seasonal variation in transparency (Figure 12). The water transparency varied from a minimum of $k = 0.309$, corresponding to a Secchi disc reading of 5.5 metres, during a diatom bloom of July 11, 1950, to maxima of

$k = 0.055$ on November 16, 1950, and on February 2, 1951, corresponding to a Secchi disc reading of 31.2 metres.

It should be noted that the minimum transparency of mid-July coincided with a diatom bloom consisting mainly of species of *Thalassiothrix*, *Rhizosolenia* and *Chaetoceras*, and a few armored dinoflagellates, mainly *Ceratium tripos*. The first winter minimum of transparency, on January 13, 1951, was associated with large numbers of nauplii and copepodites of *Oithona*, and species of *Peridinium*, *Coscinodiscus*, *Ceratium* and *Rhizosolenia*. The second, and slightly more intense reduction of transparency on February 17, 1951, was *not* associated with either nauplii or observed phytoplankton, but considerable unidentifiable detritus was noted at that time.

Comparison of the extinction coefficients with the zooplankton population signature shows very nearly an inverse proportion between the amount of zooplankton and the degree of opacity. It is apparent that numbers of zooplankton have little, if any, effect upon transparency. When the zooplankton was at its greatest numerical value, on August 1, 1950, with 16,500 animals per cubic metre of water, the clarity of the water was at its greatest for the entire summer, with $k = 0.093$. The greater part of the zooplankton at this time consisted of the copepodites of *C. finmarchicus*. On the other hand, the very small juveniles of *Oithona* may have contributed, in part, to the midwinter loss of transparency especially if the total number of nauplii were much larger than indicated owing to their passing through the mesh of the nets.

The nauplii of *Oithona* range in size from about 0.08 mm. (80μ) to 0.20 mm. (200μ) (Murphy, 1923), and the size range of the unarmored dinoflagellates is from 11μ to 212μ for the oceanic Gymnodinioidae, with a mean of about 100μ (Kofoid and Swezy, 1921). These are somewhat large as compared to the "mean" wave length of light in sea water of about 0.50μ, but certainly they should have a far greater effect upon scattering than would the nauplii of *C. finmarchicus*, which vary in size from 240μ in the first stage to 810μ in the sixth stage, and having an average length of about 2300μ in the fourth copepodite stage (Gibbons, 1923).

Owing to uncertainty as to the precise effect on transparency of particles of such irregular shapes as diatoms, dinoflagellates and small zooplankton and the unknown ratio of absorption to scattering, only the broadest qualitative statements of cause may be made at this time.

It is known that particles that approach in dimensions the wave length of light effect scattering inversely as the fourth power of their size (*cf.* Sverdrup, Johnson and Fleming, 1946, p. 87). Although it is doubtful that this premise holds true for particles the size of even the smallest zooplankton, still one would expect considerably more scattering, particle for particle, from an *Oithona* nauplius than from any stage of *Calanus*.

The filamentous diatoms in the great bloom of July 11, 1950, apparently have considerable effect upon transparency. In this case it is believed that even the maximum diameters observed for *Thalassiothrix longissima* (7μ) and *Rhizosolenia semispina* (28μ) would be within the strongly scattering size range, and could help to explain the loss of transparency at that time. If the diameters alone,

when so very small, can become important in scattering phenomena, then it would be expected that the finer appendages of some of the smaller zooplankton would also produce an effect.

No quantitative measurements were made to determine the amount of detritus in the water, but it was noted that much fine particulate matter appeared on February 17, 1951, and this may have been one of the causes of the loss of transparency at that time, for neither large numbers of *Oithona* nauplii nor small phytoplankton were noted on that date.

It is believed that fluctuations of transparency at Station "B" in 1950-1951 were due mainly to variations in the phytoplankton content and detritus present in the water, where the phytoplankton was of such morphology that it presented scattering surfaces of well less than 100μ. Except for the smallest of the zooplankton in larval stages, it is considered that living animal matter has negligible effect upon transparency. It is suspected that small unarmored dinoflagellates are responsible for some of the otherwise inexplicable sudden reductions of water clarity, in view of the fact that dinoflagellate bioluminescence ("milky" water, but no flashes) was observed during the midwinter losses of transparency.

Bioluminescence

Records of bioluminescence were made at every weekly plankton station on log sheets designed for that purpose. An arbitrary scale of values of bioluminescence was selected from the log sheet frequency column so that a histogram could be constructed to show seasonal fluctuations (Figure 13). The arbitrary

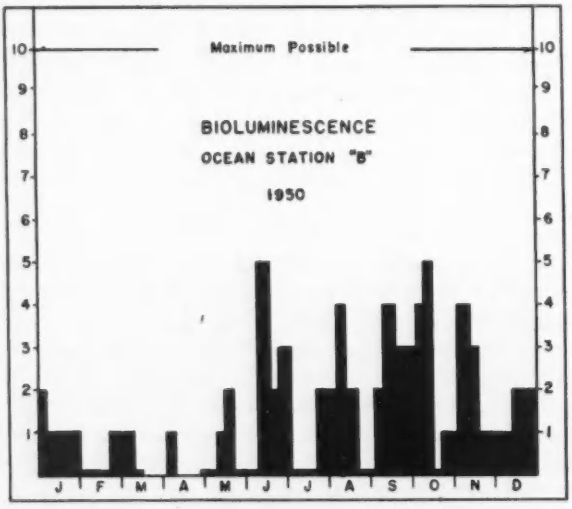


Figure 13. Bioluminescence, Ocean Station "B", 1950.

units are additive. Thus, Log Sheet Frequency values, for example, 2 and 3, would be converted to 1 and 2 arbitrary units, respectively, for a total of 3 units, and these would be plotted on the histogram (Table III).

It is considered that two major types of bioluminescence existed: (1) zooplankton, with various types of distinct flashes, and (2) phytoplankton, with momentary "glowing" of the water when disturbed. The only phytoplankton bioluminescence observed during this study was on May 17, 1950, and from January 1, 1951, through January 26, 1951. Considerable numbers of armoured dinoflagellates were noted during the latter period.

Inasmuch as the records include separate observations of at least fifteen relatively untrained individuals, the personal variations of estimate of bioluminescence are undoubtedly large, but it is believed that the results indicate at least the general trends and major fluctuations.

TABLE III. Conversion of log sheet frequency values to arbitrary units of bioluminescence.

Log sheet (frequency)	Arbitrary unit
0	0
1	1
2	1
3	2
4	3
5	2
6	3
7	4
8	5
9	8

SEASONAL WATER-MASS EXCHANGE

Indicator forms, comprising species not endemic to the Labrador Sea, have been utilized in analysing the possible exchange of water-masses in the region of Ocean Station "B". A synopsis of these is given in Table IV. Although the

TABLE IV. Seasonal appearance of indicator species.

Species	Native Region	Occurrence
Calanus hyperboreus	Arctic-boreal	Summer
Clione limacina	Arctic-boreal	Summer
Corycaeus anglicus	Boreal-subtrop.	Feb.
Euphausia krohnii	Subtrop.-boreal	Jan.
Gaidius tenuispinus	Arctic-boreal	Nov.
Halocypris globosa	E. Atl.-boreal	Feb.
Metridia lucens	South boreal	Jan.
Microcalanus pygmaeus	Arctic-boreal	Jan.
Microsetella rosea	Subtrop.-boreal	Feb.
Oncaea borealis	Arctic-boreal	Jul.
Oncaea venusta	Subtrop.-boreal	Feb.
Sagitta elegans	South boreal	Feb.
S. serratodentata	South boreal	Jan.
S. setosa	E. Atl.-boreal	Nov.
Scolecithricella ovata	South boreal	Fall

majority of these listed do not meet all of the requirements of "good" indicator species (*cf.* Sverdrup, Johnson and Fleming, 1946, pp. 865-867), the author considers the group as a whole to be highly significant as indicative of seasonal water-mass exchange.

Of these 15 species, eight boreal and subtropical appeared in the coldest part of winter, three arctic-boreal in the summer, two boreal and one arctic-boreal in the fall, and one arctic-boreal in the winter. This tends to indicate that some arctic water appears at Station "B" in the summer, and that boreal-subtropical water is found there in the winter.

There are suggested at least three agents that could account, in part, for the appearance of these subtropical forms in the region of Station "B": (1) direct replacement of the sinking northern Labrador Sea waters by surface influx from the southeast, (2) diffusion and expansion of the North Atlantic eddy, and (3) strong or continued southeast winds in wintertime.

In the first instance, Smith, Soule and Mosby (1937, p. 192) have presented the hypothesis stating that the bottom water of the North Atlantic Ocean is formed in winter by the chilling and sinking of the surface waters of the north central Labrador Sea, that subsequently flows out at great depths to the Atlantic Ocean proper. They assume that vernal warming causes the establishment of equilibrium conditions in early summer, causing partial arrest of water exchange at that time, and resulting in a general annual cycle of bottom water formation. They calculated the late summer outflow along the bottom as approximately 2×10^6 m.^{3}/sec. (Smith, Soule and Mosby, 1937, p. 173). If it is assumed that this value represents the total to be replaced from surface water from the southeast, and that the reduced wintertime influx from Irminger, East Greenland and Baffin Land Currents during this period is approximately equal to the outflow of the Labrador Current, then the approximate rate at which this replacement water enters the area may be calculated. If the effective influx area across the "mouth" of the Labrador Sea is considered to be 1000 km. wide and 100 m. deep, then the mean current velocity across that section would be approximately 2 cm./sec. This alone does not indicate sufficient rate of transport to account for the appearance of tropical forms at Station "B", but it is probable that the sinking rate (and thus the transport rate) has a considerably higher value in winter than 2×10^6 m.^{3}/sec.

Iselin (1940, p. 38) investigated the seasonal variations of transport of the entire North Atlantic eddy system and found that there was a winter reduction of transport in the Gulf Stream waters accompanied by weakening of density gradients near the water-mass interfaces which should result in a general diffusion and expansion of the eddy system. This diffusion would certainly increase the northward component of the Atlantic Drift in the vicinity of Flemish Cap, and could therefore contribute to the entry of subtropical waters into the Labrador Sea at that time.

In general, storm tracks over the western Atlantic Ocean are higher in latitude in the summer than in the winter. Also the winter storms crossing eastward from Newfoundland are more frequent and are of greater intensity than in summer. The net effect of these cyclonic winter gales is to force surface water

northward toward the region of Station "B" from the vicinity of the North Atlantic Drift. But inasmuch as quantitative data for this have not been gathered, the importance of influx by wind-driven water is unknown.

It appears most probable that the explanation of the occurrence of subtropical forms in the Labrador Sea in winter lies in a combination of the above factors, but until wintertime observations of the physical oceanography of the region are made, no assessment of the relative effects of the above agents may be suggested.

It seems probable that there is something of a reciprocal effect of water-mass exchange in the summer. The majority of the arctic and subarctic forms appear in summer, although positive indicators of arctic water are lacking in the material. There is also some physical evidence of the intrusion of cold waters from the north in the early part of June as indicated by the rise of the 38°F. isotherm at that time (Figure 4).

CONCLUSIONS

1. The zooplankton population of the central Labrador Sea is characterised by relatively few species of numerical importance, but of very large numbers of individuals. Seasonal augmentation of these species was found to take place mainly in late summer, although some winter breeding was evident.

2. The zooplankton in this region is distinct from true arctic, true boreal, and neritic populations.

3. There is definite biological evidence of the influx of boreal-subtropical surface waters into the vicinity of Ocean Station "B" in the winter.

4. Transparency varies seasonally much more in the open ocean than was previously supposed. Apparently, phytoplankton and detritus are the major factors controlling water clarity.

5. Bioluminescence varies greatly throughout the year, and is apparently unpredictable. It appears generally greatest in summer and fall.

SUMMARY

1. The zooplankton of the surface zone waters of the central Labrador Sea is comprised mainly of the following species:

(*a*) *Calanus finmarchius*.
(*b*) *Oithona atlantica*.
(*c*) *Thysanoessa longicaudata*.
(*d*) *Scolecithricella minor*.
(*e*) *Oikopleura labradoriensis*.
(*f*) *Eukrohnia hamata*.

The remainder of the species assume comparatively minor importance, and are, for the most part, immigrants in the area. In all, 61 species in seven phyla, 10 classes and 17 orders are represented in the material.

The main augmentation season for the entire population occurs in late summer, although winter breeding was noted for the copepods *Oithona atlantica*

and *Metridia longa*. It was found that the annual production of zooplankton was far greater than anticipated, and could easily support a large population at higher trophic levels.

2. The character of the zooplankton population of this region is distinctive, being neither true arctic nor true boreal. The influx of boreal, arctic and neritic waters into the region may be readily detected by means of indicator species. From the evidence supplied by these indicators, it is believed that there is a seasonal exchange of water masses in the vicinity of Ocean Station "B". Apparently, the sinking of waters in the north central Labrador Sea in winter, diffusion and expansion of the North Atlantic eddy and wintertime southeast gales contribute to the horizontal displacement of boreal-subtropical surface waters into the region.

3. Weekly Secchi disc measurements indicated that the variations of water transparency were of greater magnitude than was previously supposed. In general, the transparency is least in mid-summer, and greatest in winter, but local, transient conditions may effect water clarity radically at any time. There is evidence that phytoplankton and detritus are the major factors controlling transparency, and except possibly for juveniles of the smallest species, zooplankton has a negligible effect.

4. Bioluminescence proved to be such a variable phenomenon that no prediction of its occurrence could be made. No correlation with species or planktonic groups was found, but it was observed that the maximum amounts appeared in the summer and fall.

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